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REMOVAL OF RADIOLOGICAL, BIOLOGICAL, AND CHEMICAL CONTAMINANTS FROM WATER

Richard L. Woodward, et al

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

1959

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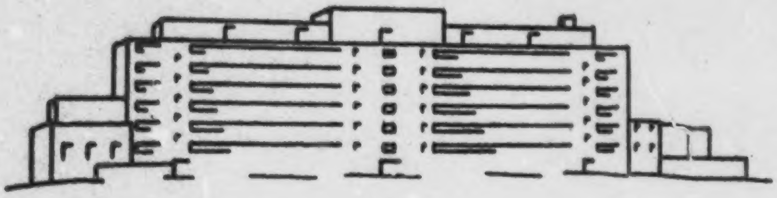

REMOVAL OF RADIOLOGICAL, BIOLOGICAL, AND CHEMICAL CONTAMINANTS FROM WATER

U.S. DEPARTMENT OF HEALTH,
EDUCATION, AND WELFARE
Public Health Service

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REMOVAL OF RADIOLOGICAL, BIOLOGICAL, AND CHEMICAL CONTAMINANTS FROM WATER

This report is a reprint of a final report to the Department of the Navy, Bureau of Yards and Docks, prepared under Project NY 300 010, Sub-project 6, entitled "Development of Practical Methods for Removal of Radiological, Biological, and Chemical Contaminants from Water Supplies". It is released with the approval of the Department of the Navy.

Richard L. Woodward and Gordon G. Robeck,

Water Supply and Water Pollution Research

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Bureau of State Services
Division of Sanitary Engineering Services

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

1959

PREFACE

The investigations described in this report were designed to meet specific requirements of the Navy, and the findings may not be directly applicable to civilian water systems. It is being issued as a report of the Robert A. Taft Sanitary Engineering Center because of numerous requests for copies which could not be met with the small number prepared initially.

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ABSTRACT

Hazard evaluation studies have shown that shore based Naval water supplies can be contaminated by chemical, biological, and radiological warfare agents. The greatest hazards to be guarded against appear to be radioactive fallout in surface waters and covert introduction of pathogenic vegetative bacteria or botulinum toxin into a water distribution system.

Laboratory and engineering studies were conducted to determine the design criteria and cost estimates of providing and operating devices to protect against these contaminants.

Small disposable columns of mixed cation-anion exchange resins will remove the soluble radionuclides enough to suffice for immediate drinking and culinary purposes near the point of use, providing a 99 percent removal will lower the radioactivity level to 0.1 μc/ml.

Chlorination sufficient to provide free available chlorine residuals of at least 1 mg/liter after an assured contact period of 5 minutes will destroy 99.9 to 99.99 percent of the most likely BW agents.

Chemical warfare agents are so numerous and varied that it would not be feasible to provide a single protective device to cope with them. In general, the standard chemical warfare agents are less suitable as intentional water contaminants than some of the biological agents. Some of the chemical agents now being developed may be more dangerous as water contaminants than the standard agents.

DEVELOPMENT OF PRACTICAL METHODS FOR REMOVAL OF RADIOLOGICAL, BIOLOGICAL, AND CHEMICAL CONTAMINANTS FROM WATER SUPPLIES

INTRODUCTION

The purpose of this project has been to develop design criteria and operating procedures for water treatment plants intended to remove or inactivate radiological, biological, and chemical warfare agents that may be encountered at continental Naval Bases in the United States.

Investigation has shown that one set of design criteria is not feasible for general application, but that the purpose of the project can be accomplished better by considering two typical plants as follows:

1. A plant for typical continental Naval Base, using water from an open reservoir or river, not normally contaminated by excessive sewage or industrial wastes, capable of providing about 1,000,000 gal/day of potable water. The plant is to operate normally in peace-time, but be capable of handling the radiological, biological, or chemical attacks on short notice in the event of contamination of the raw water.
2. A plant for removal of these special warfare contaminants only, to be cut into a potable water system in event of actual or expected attack. This assumes contamination of water after undergoing ordinary treatment. This type of plant would be located near the point of consumption. Approximate capacity about 100,000 gal/day.

This report will not cover other situations such as using groundwater, although it is understood that stored water from covered tanks, bottles, or the ground would be the most effective protection against these contaminants.

Even when the water supply conditions are as limited as the two given above, it is apparent that no one treatment will suffice for all three types of warfare agents at one time. Therefore, each type of agent will be considered separately and any combination of devices can be discussed later.

RADIOLOGICAL

Before presenting the design criteria that have been developed, it is advisable to review some of the findings of the hazard evaluation studies made in connection with this project, and the information available on detection and present treatment of warfare agents since such considerations play an important role in determining design of protective measures.

HAZARD

Short-Term Basis

The principal hazard to be guarded against is contamination of surface waters by primary fallout from high yield nuclear weapons. From the information available, it has not been possible to evaluate all of the pertinent factors affecting the hazard likely to be encountered. However, it is apparent that water contamination is not likely to significantly reduce the military effectiveness of personnel using it, except where the general level of contamination is extremely heavy (greater than 1,000 r/hour at H+1.) Under such circumstances external radiation will be the major hazard, and water contamination will contribute significantly to the radiation dose only where effective shelter is provided to reduce external radiation exposure.

Calculations of the radiation dose to various organs due to ingestion of water contaminated by fresh mixed fission products indicate that the gastrointestinal tract is the most heavily irradiated organ of the body under conditions of short time ingestion.

To determine permissible levels of activity in water under emergency conditions, it is necessary to decide the radiation dose acceptable under the circumstances. If a dose of 100 rem to the G.I. tract in 10 days is acceptable, water with an activity of 0.4 μc/ml at D + 1 can be used for 10 days. On the other hand, if the maximum acceptable internal dose is 15 rem in a 90-day period, the acceptable water activity level at D + 1 is approximately 3×10^{-2} μc/ml. There is little information available upon which to estimate dose-effect relationships for radiation doses due to short time ingestion of radioactive materials.

Many radiation biologists consider that the greatest hazard from ingestion of mixed fission product radioactivity is due to the increase in body burden of Sr^{90} and that radiation damage to other organs and by other nuclides is of secondary importance.

Therefore, during early times after fallout when external radiation levels are highest the hazard from ingestion of a given amount of mixed fission product activity is much less than for a comparable amount of activity at later times when the percentage of Sr^{90} in the mixed activity is greater.

Radiochemical studies of Nevada primary fallout in water further indicates a preferential strontium dissolution five times greater than beta emitters in general. This means that if the MPC is to be based on strontium body burden, then a 0.1 μc/ml value should be lowered in proportion to the degree of strontium fractionation.

In Appendix A are results of fallout studies made during the 1957 Nevada test series. It also has computations of the levels of activity of ideal fission product mixtures of various ages that would lead to a body burden of 5 μc of Sr^{90} if used for one year together with estimates of radiation dose to the gut and to the skeleton due to use of such water.

From these considerations it would appear that maximum permissible concentrations of radioactivity in drinking water under military emergency conditions might well be in the order of 0.1 μc/ml during the early period after attack and that at later times considerably lower levels should be permitted to guard against the accumulation of Sr^{90}.

It has been pointed out in earlier progress reports and in Appendix A that conventional water treatment processes are relatively inefficient in removing those soluble radioactive isotopes which present the greatest hazard when ingested (10 to 70 percent, depending upon the isotope.) On the other hand, they do effectively remove the insoluble particulate matter. If further decontamination is required, only two processes are worthy of serious consideration, namely, ion-exchange and distillation.

For waters of mineral content suitable for drinking, distillation is considerably more expensive than ion-exchange demineralization. Therefore, consideration has been limited to various schemes utilizing ion-exchange materials for removal of soluble radioactive contamination.

The most significant fission products to be considered during the immediate period after fallout are Sr^{89}, Y^{91}, Zr^{95}, Mo^{99}, Ru^{103}, Te^{132}, I^{131}, I^{132}, Ba^{140}, La^{140}, and the rare earths. Since such a mixture contains considerable amounts of hazardous radioactive anions, notably iodine isotopes, removal of both cations and anions is required. To do this, a column of mixed cation-anion exchange resins is needed. Such a column will remove 99 percent of the radionuclides remaining in a normal water treatment plant effluent. The quantity and cost of these resins will depend upon the mineral content of the water rather than its radioactivity since most exchange sites will be occupied by stable rather than radioactive ions. Break through of either type ion will occur at approximately the same time.

Long-Term Basis

As the fission products decay, a larger percentage of the activity is due to the more dangerous long-lived isotopes, i.e., capable of serious internal damage. Outstanding among these isotopes is Sr^{90}. As this occurs the problem becomes one of protection against a long-term hazard.

It is not possible to predict to what extent decontamination facilities are likely to be needed since surface water supplies are dynamic and individual. The determination of need should be based on radiochemical analysis for such nuclides as Sr^{90} and Cs^{137}. Treatment facilities need not be provided in advance of demonstrated need.

Facilities and competence for such analyses should be available at the Naval District level or arrangements should be made with other governmental, or with private laboratories.

Treatment of water contaminated with the longer lived nuclides can best be done with cation ion-exchange resins.

No consideration has been given to development of design criteria for protection against radioactive materials covertly introduced. They have been dismissed as relatively unimportant since they appear unsuited as a means of sabotage when compared to biological or chemical methods.

DESIGN CRITERIA

Where only surface water is available, conventional water treatment processes must suffice for the large requirements likely to be needed for decontamination of radioactive surfaces, and for fire protection. Ion-exchange and distillation are not economically feasible as a treatment method for these uses.

It is anticipated that for the first 10 days, the immediate period, a supply of one gallon per person per day will suffice for drinking and culinary purposes. This figure represents roughly 1/100 of the average water demand. For an installation with an average water use of 1,000,000 gallons per day, it will be necessary then to supply 10,000 gallons per day of water that is safe for drinking and culinary purposes. Ion-exchange treatment is the most practical and economical method of supplying this water.

Since the fresh fission products contain activity due to anions as well as cations a mixed bed ion-exchange column will be required. The anions are mostly short-lived isotopes and a cation bed alone will suffice for the long-term requirements.

TYPE, SIZE, AND COST OF UNITS

Immediate Demand

Although a centrally located and operated demineralizer could produce water more economically than smaller more widely dispersed units, it has not been considered as the most desirable solution because of the problem of distributing the water. At times when such treatment would be needed, it would be most important to avoid all unnecessary exposure to external radiation. Distribution of a centrally treated supply for drinking and culinary purposes by tank truck or other means would involve considerable radiation exposure to personnel involved which could be avoided by providing numerous small demineralizers in shelters or at other points of water use for decontaminating the piped water supply.

Small, mixed-bed demineralizers similar to those in common use in laboratories would be equipped with disposable cartridges containing the ion-exchange resins. A simple conductivity meter or resin color change would indicate the need for replacement of an exhausted cartridge. This type of apparatus is recommended to supply the immediate requirements for all installations.

The typical cost estimates presented in Table I for small demineralizers are based upon the following conditions:

1. Total solids content of water to be treated is 10 grains per gallon which is an average quality. (1 grain per gallon = 17.1 mg/liter).
2. Flow rate of 5 gallon per hour. (2 gallon per minute/cu. ft.)

3. Each demineralizer cartridge has a capacity for 1100 grains of dissolved solids. (Approximately 1.5 foot long and 2 inches in diameter.)
4. Maximum cartridge changes of one per day. Discard each cartridge safely since it will be radioactive and thus not practical to regenerate.

TABLE I

COST OF DEMINERALIZING RADIOACTIVE WATER FOR SHORT TERM

Water Demand gpd	Cartridges Required per day[1]	Initial Cost of Complete Units at $81. each	Operating Cost Based on Cartridge Needs
10,000	90	$7300.	$ 870.
5,000	45	3650.	435.
1,000	9	730.	87. (9 cents/gal.)

([1]Based on removal capacity. Where the total solids in the water are less, the operating cost will be less.)

It is possible to use a much simpler throw-away ion-exchange cartridge and holder, providing it is not put into a pressure line. The capacity for such a model is 900 grains with a rate of 5 gph. The initial wall bracket support, faucets, hose connections, etc. would cost about $7.50 each and the replaceable cartridge about $9.50. Prices would vary with size of order, but a 30 percent reduction is possible. This would reduce the initial cost by a factor of ten, but the operating costs would be about the same.

Long-Term Demand

Pressure cation-exchange beds operated on the sodium cycle are the preferred method of decontaminating water for drinking and culinary purposes where this is necessary on a long-term basis because of contamination by Sr^{90} and other long-lived radionuclides. This equipment would normally be located at the water treatment plant and operated by that plant's personnel. Where the water is comparatively soft, it may be economically feasible to treat the entire water supply. Where the water is hard, it may be preferable to treat only enough for drinking and cooking, and to make special provisions for distribution of this water with proper sanitary precautions.

The cost estimates in Table II for such units are based upon the following conditions:

1. Hardness of water to be treated: 8 grains per gallon.
2. A maximum flow rate: 8 gallons per minute/ft^2.
3. A high capacity styrene resin will be used, such as Dowex-50 or Amberlite IR-120.
4. Capacity of resin is 30 kilograins per cubic foot.
5. Amount of regenerant required is 16 lbs. per cubic foot.
6. For maximum demand, regeneration would be required once a day.

TABLE II

COST OF DEMINERALIZING RADIOACTIVE WATER FOR LONG-TERM DEMAND

Aver. Water Requirement 1000 gal. per day	Max. Water Requirement 1000 gal. per day	Tanks		Bed Depth ft.	Bed Volume ft^3	Initial Cost	Operating Cost per 1000 gal.
		No.	Dia. ft.				
100	300	2	4.5	2.52	80	$15,000	$ 0.1555
50	150	2	3	2.83	40	10,000	0.175

Costs will vary somewhat depending on water hardness and extent of treatment required for a particular situation, and this can only be evaluated when the problem is at hand. These costs do not reflect the cost of distribution of the water with proper sanitary precautions. At most bases it will probably be more economical to obtain the necessary water from safe ground water sources rather than to resort to this special treatment.

BIOLOGICAL

HAZARD

A number of biological agents could be used quite effectively to contaminate water supplies. The most effective method of using these materials would be by their covert introduction into a water distribution system.

If introduced into the raw water, normal treatment processes would remove or destroy a considerable fraction of most biological agents; and although they might not produce a completely safe water, they would provide some degree of protection; or, conversely, an enemy would need to use larger quantities of the agents to penetrate this defense.

Information on the casualty producing dose of most biological agents is scant, but some is available. This has been discussed in previous reports. The agents which appear most effective for use as casualty producers in water are the various vegetative pathogenic bacteria, and botulinum toxin. It is not possible to rule out entirely the use of pathogenic spore-forming bacteria, notably B. anthracis, but this organism is not especially infectious by the oral route. If it were used, very large doses of the agent would probably be required to produce casualties.

Viruses have been considered as possible water contaminants, but are considered less suitable agents than bacteria or botulinum toxin. They are more difficult to produce in quantity than bacterial agents or botulinum toxin, particularly in the absence of specialized production facilities. There is very little information on the infectious dosage of viral agents, but most quantities of the viruses would probably be needed to infect a sizeable proportion of the population via the water route. Epidemiological evidence indicates that infectious hepatitis is the only serious virus disease frequently spread by water. No method of growing this virus outside the human body is known at present.

Our knowledge of the effectiveness of chlorine in inactivating viruses is incomplete. The enteric viruses that have been studied show a wider spectrum of chlorine resistance than the vegetative bacteria. Some are killed by very low chlorine doses, but some appear to be more resistant to chlorine than vegetative bacteria.

Other biological agents might also be used but from the information presently available, it appears that these mentioned above would present the greatest hazard.

One potential agent which has not been considered in design is the toxin found in some shellfish and produced by certain dinoflagelates such as Gonyaulax catanella. This poison has been responsible for more than 600 known cases of poisoning and some 69 deaths. The toxin has been prepared in crystalline form and it may be possible to synthesize it but as present the only source is infected shellfish or the organisms producing it. The lethal dose to man as established from accidental human poisoning is approximately

3-5 mg of the pure toxin. At present, production of large amounts of the toxin would be very difficult and expensive, but if a suitable method of synthesizing the compound could be developed, this would be an outstanding agent for contamination of water or food.

The quantities of shellfish toxin available for use on this project were sufficient to permit only limited study of possible water decontamination. This toxin is relatively stable to heat except at high pH. It is removed by cation exchange materials, under certain conditions, and destroyed to some extent by chlorine dioxide. Details of limited studies conducted at this Center on the effectiveness of chlorine and chlorine dioxide in destroying shellfish toxin are presented in Appendix B.

No method is available for quickly detecting contamination of water by biological warfare agents. For this reason any protective measures taken must be routine once it has been determined that danger of an attack exists.

The closest approach that exists for quick detection of BW contamination is through continuous measurement of free chlorine residuals. Since most of the suitable biological agents are killed or inactivated by chlorine, an enemy would probably introduce a dechlorinating agent along with the BW agent.

If chlorine residual levels in the distribution system are sufficiently constant or slowly varying and if they are normally sufficiently high to cause appreciable destruction of BW agents, this procedure could provide some warning and a degree of protection. Relatively little information is available on the normal variation of chlorine residuals in water distribution systems. To obtain some information on this question automatic chlorine residual recorders were operated at two Public Health Service installations located at different points on the same distribution system. At one location chlorine residual levels varied slowly and never approached zero. At the other location, however, there were frequent periods of zero residual and variations were wild and precipitous. Variations from zero to several mg/l occurred in 15 minutes or less on a number of occasions.

Thus the feasibility of relying on a chlorine residual recorder to warn of contamination by BW agents would have to be determined by study of each situation.

Several methods of disinfection for protection against BW agents have been considered and reported on in separate reports. The ones which hold the most promise are chlorine, chlorine dioxide, and heat. Each has its advantages and disadvantages for a particular situation. The effectiveness of all three are a function of concentration and time.

Chlorine

The relationship between free available chlorine concentration (C) and chlorine contact time (t) for a stated kill (other variables constant) is usually expressed by $C^n t = K$. The value of K depends on the organism to be killed, as well as pH and temperature. For vegetative bacteria, it is very low; for bacterial spores, it is high; and for botulinum toxin, it is between these two extremes.

When using free available chlorine, the active agent mainly responsible for destruction of both spores and vegetative bacteria is undissociated HOCl, (hypochlorous acid). When HOCl ionizes to H^+ and OCl^- in water, it loses most bactericidal properties. At pH values above 7.0 this ionization becomes appreciable. For this reason, the pH of water must be held in the range from 6.0 - 7.0 for efficient spore kill. For vegetative bacteria, no pH adjustment is considered necessary unless the pH is in excess of 9.5. The ability of free chlorine to destroy botulinum toxin is not markedly effected by pH. Most water will have a "chlorine demand" that must be satisfied before free available chlorine residuals will exist. It is necessary then to measure free chlorine residuals after the contact time has been provided. Combined chlorine residuals are much less effective against all of these agents and cannot be recommended.

The actual operating residual necessary to kill vegetative bacteria rapidly is generally only a fraction of a mg per liter. Although the resistance of toxins to chlorination varies widely, all five types of botulinum toxin tested in this laboratory were at least 99.9 percent destroyed in five minutes or less by providing a free available chlorine residual of 1 mg/l.

Bacterial spores are many times more resistant to chlorination than vegetative bacteria. Higher chlorine concentrations, longer contact times and special attention to pH control are needed to protect against spores. Because of these special requirements and because of the doubtful effectiveness of B. anthracis as a water contaminant separate recommendations are included for protection against bacterial spores.

Chlorine is the standard water disinfectant and there is a considerable background of experience in its use. Reliable equipment is readily available to feed chlorine at rates proportional to flow. Automatic chlorine residual recorders are available which will differentiate between free and combined chlorine.

Chlorine dioxide

Chlorine dioxide is somewhat more effective than free available chlorine in destroying botulinum toxin. A major advantage of chlorine dioxide is that it does not react as chlorine does with ammonia that may be present. This means less chlorine dioxide will be necessary to destroy the harmful ingredient, toxin.

The principal difficulties which prevent recommending it instead of chlorine are incomplete knowledge as to its effectiveness as a bactericide and uncertainty as to methods of measuring chlorine dioxide residuals in water. It is also more expensive than chlorine.

Heat

Heat is the oldest most widely used and probably the most reliable method of disinfection. Pathogenic vegetative bacteria and viruses are killed in a few seconds at 70°C. Botulinum toxin requires temperatures in the neighborhood of 80 - 100°C for rapid destruction. Shellfish poison can be destroyed by heat at pH's above 9.0. Bacterial spores require much higher temperatures.

Reliable automatic equipment for controlling heat disinfection processes is readily available. The operating cost is high as compared with chemical water disinfection even though heat exchangers may be used to recover much of the heat. Equipment cost is also high as compared with that needed for chemical disinfection except for very small installations. Appreciable variations in flow make for greatly decreased efficiency of operation and increased equipment cost of heat disinfection.

For very small installations where freedom from operation problems is of prime importance heat has considerable merit. Heat exchangers designed for very small installations; such as, individual homes, rural schools, isolated recreation areas, etc., are under test at the Sanitary Engineering Center and results are encouraging. These must operate at a low rate for a high percentage of the time in order to be reasonably economical. This requires storage and pumping in order to provide water at demand.

For general use the high cost of heat treatment of water makes it less desirable than chlorination. For small installations or for special portions of larger installations, it may be reasonable in cost.

It should be emphasized that although the recommendations made for protection against various biological agents are believed to be adequate, it is not possible to give absolute assurance on this. The possibility of development of more dangerous or more chlorine resistant strains of particular organisms exists, as does the possibility of developing feasible methods of producing materials such as shellfish toxin and infectious hepatitis virus which have not been considered as potential agents at this time.

DESIGN CRITERIA

Raw Water Contamination

Somewhat less attention has been paid to the details of protection against raw water contamination since it can be more easily handled than contamination of finished water. As a means of conducting biological warfare, contaminating a raw water with a biological agent could not be a notable effective method, especially since one of the prime purposes of a water treatment plant is to remove micro-organisms. Nevertheless, suggested protective measures are presented here to illustrate how existing treatment plants may be strengthened or altered to cope with various BW warfare agents introduced into a raw water supply.

For vegetative bacteria and botulinum toxin separately or together these measures are:

1. Chlorinate the raw water so there is a free available chlorine residual of 0.6 mg/l in the influent to the filters.
2. Monitor this residual by providing a continuous, automatic chlorine indicator and recorder.
3. Arrange for the instrument to sound an alarm when the residual drops below 0.5 mg/l.
4. If free residual chlorine drops below 0.5 mg/l prior to filtration, increase chlorine feed to overcome decrease and increase post-chlorine feed to give 1.0 mg/l free chlorine residual in the water leaving the plant.
5. At other times post-chlorinate to maintain a residual of 0.5 mg/l in the water leaving the plant.

These recommendations are based on an assumption of a pH level below 9.5 and a nominal detention time between prechlorination and filtration of not less than 2 hours.

This treatment will be adequate except in lime softening plants where the pH may be too high for effective bactericidal action of chlorine at these recommended dose levels and in plants using upflow clarifiers with short detention periods.

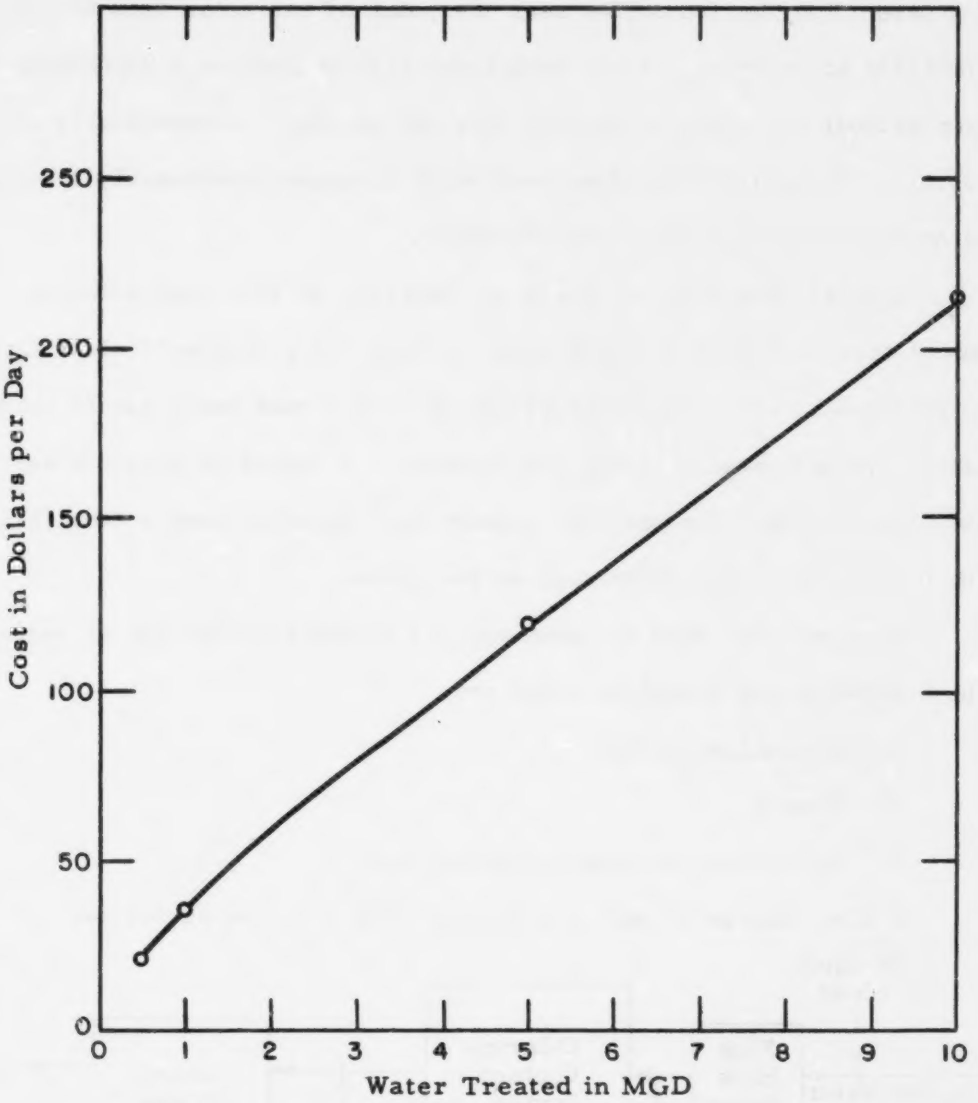
In plants where the normal fluctuation of chlorine demand is appreciable, somewhat higher residuals than are recommended above may need to be carried routinely in order to prevent too frequent drops below the alarm level of 0.5 mg/l.

The cost of this protection is relatively low. The largest equipment item would be an automatic indicator, recorder, and alarm which would cost about $3500 for any size installation. Larger chlorine requirements would be the principal operating expense.

For protection against bacterial spores the special measures are:

1. Chlorinate the raw water so as to maintain a 17 mg/l residual of free available chlorine in the influent to the filters. The nominal flow through time of 2 hours will provide enough contact time to affect a 99.9 to 99.99 percent inactivation of spores.
2. Monitor this residual with an automatic and continuous chlorine residual indicator and recorder, equipped with an alarm to indicate when the residual drops below 15 mg/l.
3. Provide an automatic and continuous pH indicator and recorder with an alarm. It should also be placed just ahead of the sand filters to make sure the pH is no higher than 7.5 since disinfection action is impaired in a higher pH range.
4. Provide sulfur dioxide feed for reducing the final chlorine residual to 0.5 mg/l.
5. If either alarm is sounded take the necessary corrective action and discontinue dechlorination.

As illustrated in Figure 1 and in Appendix E, the estimated cost of providing this supplemental treatment will vary from $22 per day for 0.5 MGD to $215 per day for 10 MGD.



ESTIMATED COST OF MODIFYING A CONVENTIONAL WATER TREATMENT PLANT TO INSURE BACTERIAL SPORE INACTIVATION

Figure 1

Finished Water Contamination

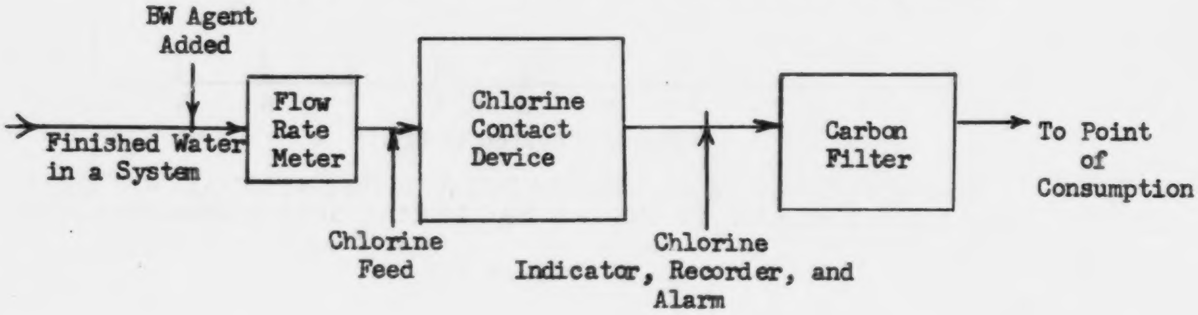
The principal design problems in protection against BW contamination of a water distribution system near the point of use arise from the desirability of carrying out the decontamination process on a continuous flow basis without appreciable pressure loss and as nearly automatically as possible. Repumping after treatment would increase considerably the cost and operating complexity of the procedure.

Special attention is needed in designing an efficient chlorine contact tank to assure that all water is held for a time sufficient for the chlorine to act. Short circuiting in such a tank could permit inadequately treated water to reach the consumer. A number of possible designs have been studied. The one that appears most suitable uses a tank filled with a coarse granular media such as pea gravel.

Measures that must be taken against covert introduction of vegetative bacteria and botulinum toxin are:

1. Superchlorination
2. Detention
3. Dechlorination with activated carbon

A flow diagram of such a treatment unit would be as follows:

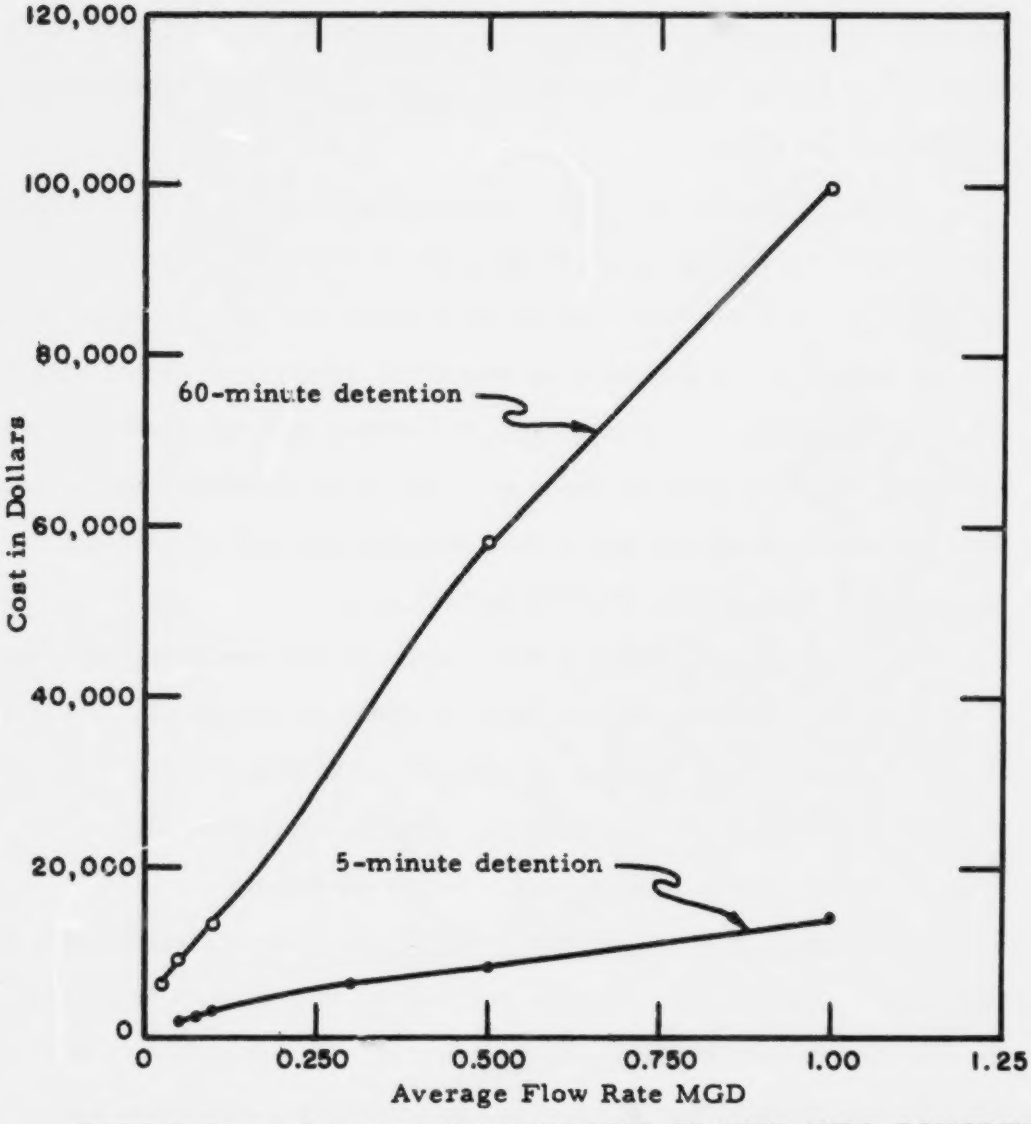

BW Agent Added
Finished Water in a System
Flow Rate Meter
Chlorine Contact Device
Carbon Filter
To Point of Consumption
Chlorine Feed
Chlorine Indicator, Recorder, and Alarm

Flow Rate Meter: The primary purpose of the flow meter is to provide the control signal for the chlorine feed. Either a propeller type or a positive displacement type meter should be selected, depending on the rate of flow. It should be capable of proportioning feed over the range of flows expected. Where this is greater than 10 to 1, the meter should be chosen to signal accurately at peak flows and, if necessary, overfeed at low flows.

Chlorine Feeder: For small installation, a pump of the proportioning type to feed calcium hypochlorite solution is preferred, since it is cheaper and does not require special safety precautions such as are needed in handling gaseous chlorine. It will be more economical to use gaseous chlorine for large installations. In either case, the device must be capable of proportioning the feed over the range of flows to be expected. Sufficient chlorine must be added so that a free chlorine residual of at least 1 mg/l is maintained throughout the chlorine contact time.

Chlorine Contact Device: The details on the developing and testing of this special chlorine contact tank are given in Appendix D. The construction cost of such a device is illustrated in Figure 2 as it varies with size and detention time. For example, it would cost about $14,000 to build a tank to handle 1 MGD with a 5-minute detention.

Chlorine Indicator, Recorder, and Alarm: This instrument will continuously record the free chlorine residual of the water at the outlet of the chlorine contact device. In the event of a covert attack, a dechlorinating chemical can be expected to accompany a biological agent. An alarm, activated by this instrument, should be provided to warn of this.



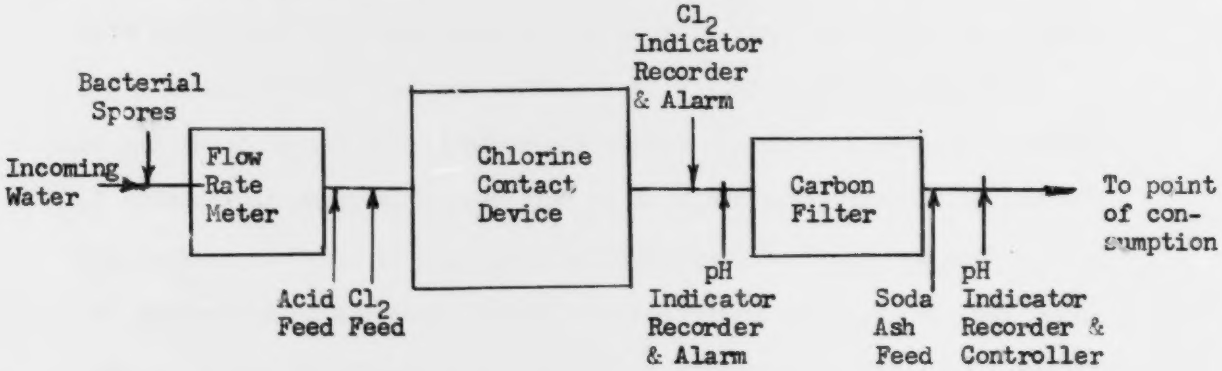
ESTIMATED COST OF CONSTRUCTING GRAVEL FILL CONCRETE TANK FOR USE AS CHLORINE CONTACT TANK

Figure 2

Activated Carbon Filter: Pressure type, granular carbon filters are provided to dechlorinate the water. They should be 30 inches deep, and designed for 3 gal/ft^2/min at the maximum flow rate. The carbon will, in addition, provide some protection against chemical warfare agents. A discussion of the engineering practicability of dechlorination by using activated carbon filters is given in Appendix C, Part I; and Part II summarizes the work done here on using these filters to remove botulinum toxin.

A special building to house the equipment will be unnecessary for most installations, since it is compact and a suitable space can probably be located in existing structures. The detention tank can be placed underground or at ground level out-of-doors.

To provide protection against the covert introduction of bacterial spores, a few additional devices and chemicals must be used so that the entire flow diagram would be:


Bacterial Spores
Incoming Water
Flow Rate Meter
Acid Feed
Cl_2 Feed
Chlorine Contact Device
Cl_2 Indicator Recorder & Alarm
pH Indicator Recorder & Alarm
Carbon Filter
Soda Ash Feed
pH Indicator Recorder & Controller
To point of consumption

The function and size of each unit would be similar to those discussed previously except for control of pH.

Acid Feed: A proportioning feed pump should be provided to add acid. The pump will be controlled by the signal from the flow rate meter, and should be capable of adding sufficient acid to insure a pH of 6.0 - 6.2 at the peak flows. Acid feed will not be required at every installation since pH of many water supplies will be sufficiently depressed by the chlorine feed alone.

Chlorine Feed: A device to feed gaseous chlorine should be provided. Chlorine gas will aid in depressing the pH and is more economical for this type of installation than hypochlorite. The chlorinator must be of the automatically proportioning type since it will be controlled by the flow meter, and capable of feeding accurately at the maximum flow rate expected. A free chlorine residual of at least 15 mg/l must be maintained after the contact time. The amount added will be more than this, of course; it will depend on the chlorine demand of the water and whether or not chlorine is the only chemical added to depress the pH. In many cases, this will be found more economical than installing and operating acid feed equipment.

Chlorine Contact Device: A chlorine contact tank filled with pea gravel should be provided to detain the maximum flow for at least one hour. The design, construction and cost of this device is given in Appendix E.

Soda Ash Feed: A proportioning feed pump is provided to feed soda ash. The pump will be controlled by a signal from the pH instrument to follow. Soda ash is necessary to increase the alkalinity and pH of the water after dechlorination and to reduce its aggressiveness. The pump should be capable of proportioning over the range of flows expected.

pH Indicator, Recorder, and Controller: This instrument will originate the control signal for the soda ash feed pump. It should be capable of controlling over the range of flows to be expected. In addition, the instrument will provide a permanent record of the pH of the water distributed for consumption.

For most installations, a special building to house the equipment will be required; the size will, in effect, depend on the flow.

As indicated in Figure 3, the daily cost of this retreatment against spores varies with flow from $43 per day for 0.1 MGD to $268 per day for 1 MGD. On the other hand, for other BW agents the cost would be only $16 per day for 0.1 MGD to $94 per day for 1 MGD.

For estimating costs, only the prices of water treatment equipment commercially available have been used. Equipment has been amortized over 10 years at 2.5 percent interest. In addition to the major items of equipment, the cost includes estimates of:

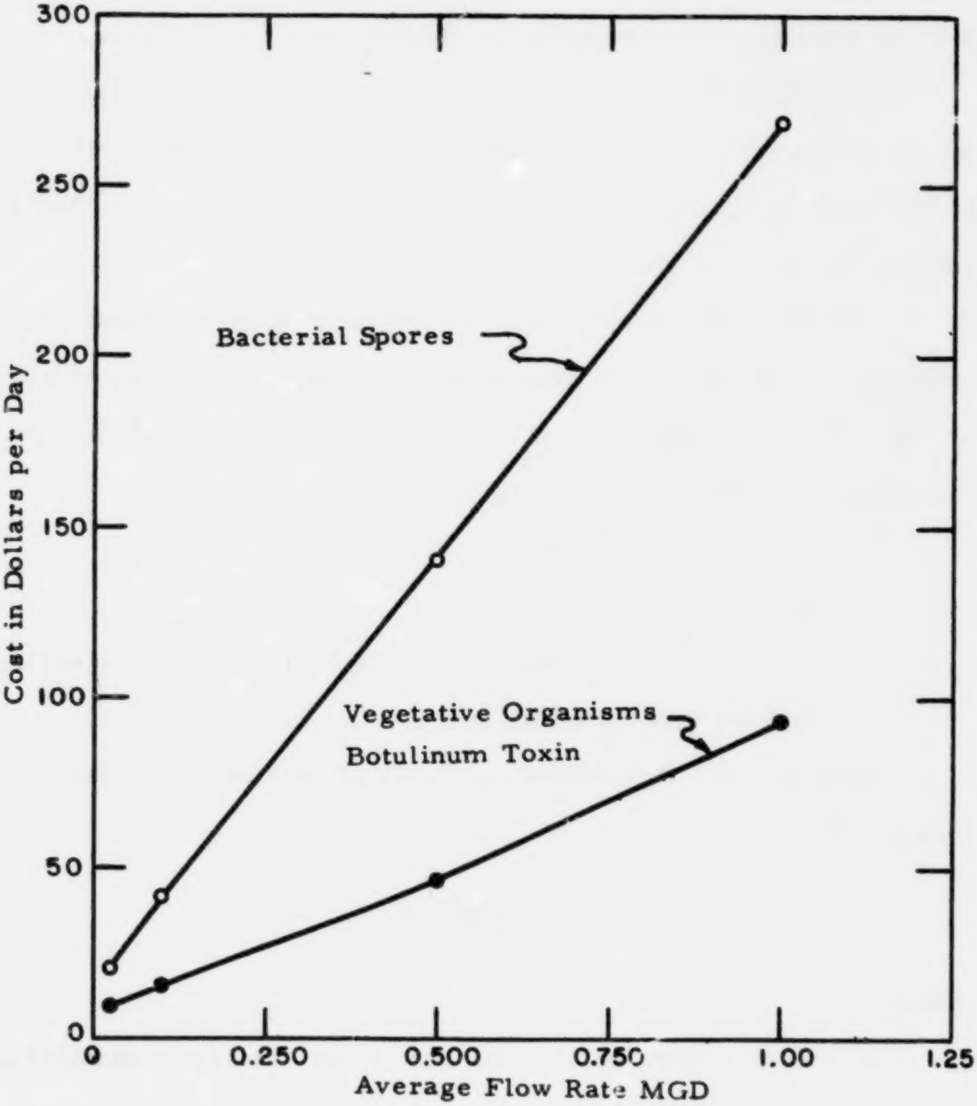
1. Installation (in the U.S.)
2. Necessary piping for hookup
3. Miscellaneous equipment likely to be required for operation
4. Maximum daily chemical use.

Detailed cost figures for all types of treatment are presented in Appendix E.

CHEMICAL

HAZARD

As covert contaminants in finished water, available chemical warfare agents generally would be less suitable than biological agents. Most chemical poisons are relatively quick acting at levels which would cause casualties and their presence would probably be noted before a large fraction of the potential water users would be affected. In addition,



ESTIMATED RETREATMENT COST

Figure 3

the oral toxicity of even the nerve gases (among the most potent chemical agents) is such that comparatively large quantities of material would be required to contaminate a water supply.

Contamination of a raw water source with chemical agents would require more material than contamination of a finished water and would be a less effective method of reaching the target population. Raw water contamination incidental to use of chemical agents in air is, however, a possibility and provision for emergency measures to deal with this contingency should be provided.

The Army Chemical Corps has developed a kit for detection of the common CW agents in water. This kit, stocked by the Navy Department, would be particularly suitable for use at water treatment plants for detection of contamination of the raw water incidental to a general CW attack.

To detect covert attacks using chemical agents, some type of continuous monitor would be desirable. As a possible device for this use, a continuous bio-assay technique using fish has been developed at this Center. (See Appendix F for details). Fish are much more sensitive than humans to many chemical contaminants, and they are particularly sensitive to the nerve gases. Concentrations of the nerve gas GB in water which can be tolerated by humans are rapidly lethal to fish. The procedure is subject to some "false alarm" difficulties since certain materials harmless to humans are toxic to fish. This procedure is not suited to detection of biological warfare agents. Fish are not sufficiently affected by botulinum toxin or staphylococcus enterotoxin to be useful for detecting these two potential agents.

There are no economically feasible water treatment methods which could be routinely applied to a water supply to remove or destroy all known chemical warfare agents. Granular activated carbon filters, such as are recommended for dechlorination in the protection against BW agents, will provide some protection against many chemical agents and are about as close an approach to a general protective device as is available. (See Appendix C, Part III). Specific decontamination procedures, which have been worked out by the Army Chemical Corps, will be required when contamination is discovered and the agent identified. For nerve gases this is accomplished by adjusting the pH to promote rapid hydrolysis which reduces the toxicity of nerve gases.

DESIGN CRITERIA

In developing general design criteria major consideration has been given to protection against the nerve gases in water. It should be pointed out, however, that the possibility of using still other known chemicals does exist, as well as the possibility of development of new agents. Since decontamination procedures must be tailored to the particular chemical involved, it is not feasible or even possible to prescribe a routine or single treatment method suitable for all agents.

Raw Water Contamination

As indicated previously, the most practical basis for counteracting nerve gases in water is to raise the pH to increase the rate of hydrolysis. This would be done routinely where the water is softened by a lime-soda ash process. In other cases, an alkali such as lime or soda ash could be added to a raw water when detection methods indicate nerve gas contamination. The resulting high pH, of course, would greatly reduce the disinfecting power of chlorine and hence would not be desirable if concurrent BW contamination was suspected.

Finished Water Contamination

The activated carbon filters designed for dechlorinating and discussed previously will help to remove the nerve gas GB. However, installing these filters specifically for chemical warfare agents would not be practical since there are other CW agents that would not be removed by activated carbon. The activated carbons most suitable for removal of chemical warfare agents are not the most suitable for dechlorination and vice versa.

SUMMARY

It is difficult and costly to design and operate a treatment plant to protect all water from all possible biological, chemical, and radiological warfare agents. It usually will be practical to protect only against the most likely incidents and agents. These possibilities appear to be primary fallout from high-yield nuclear devices, and covert introduction of vegetative bacteria or botulinum toxin into finished water.

During the immediate period following heavy contamination of a surface water supply by radioactive fallout the most feasible method of decontamination of the water will be by small mixed-bed ion-exchange columns. Such a column will remove about 99 percent of the soluble radioactivity from the water. This treatment will cost approximately $0.10 per gallon so it should be limited to water for drinking and food preparation. These treatment devices should be located in shelter areas near the point of water use.

Chlorination with free available chlorine residuals of 1 mg/l will suffice to handle most BW agents, but the time, temperature and pH all have some influence on its effectiveness. A detention device made up of a reinforced concrete tank filled with pea gravel will serve to obtain the maximum use of chlorine in the shortest time when installed in a finished water pressure system. In conjunction with this device, it would be necessary to have equipment that would control the chlorine residual and in some cases the pH. This type of retreatment would cost $16.00 per day for 0.1 MGD and would need to be operated routinely when there is reason to believe danger of a BW attack exists.

APPENDIX A

FALLOUT STUDIES

Samples of fallout from the Nevada balloon shot "Priscilla", detonated June 24, 1957, were collected in fallout trays at various distances from ground zero and put through a size separation process to obtain particles in three size ranges, <5 microns, 5 to 50 microns, and >50 microns. The samples were shipped to this Center for solubility tests and radiochemical analysis. The field work was done jointly with representatives of the Corps of Engineers, Engineer Research and Development Laboratory.

TEST PROCEDURES

A gross beta activity determination was made on each sample by counting the radioactivity in a raw soil portion with a GM counter and also in an acid-dissolved portion with an internal, gas-flow, proportional counter. Decay rates on these samples were determined over a 6-month period.

Another portion of each soil sample was mixed thoroughly with 10 liters of distilled water for 1 to 2 minutes daily and then allowed to stand. The pH was adjusted to approximately 7 by adding a small amount of $1\underline{N}$ HNO_3.

To obtain a representative sample of this slurry a rapid mixer was used for a few minutes before and during the siphoning of two 100 ml portions. These duplicate samples were filtered through a membrane filter to separate the suspended solids. Both the suspended and liquid portions were dried, plated, and assayed for gross beta activity with an internal proportional counter. The same sampling technique was employed to obtain portions for subsequent radiochemical analysis.

SOLUBILITY OF FALLOUT

As indicated in Table I, about 10 percent of the radioactive material in each particle size range usually went into solution. However, the fine dust (<5 microns), at approximately 4,000 yards from ground zero, was only about 3 percent soluble. There is no apparent reason for this low value especially since the particles in the same size range from a near ground zero sample were 10 percent soluble. The activity per unit weight of this fine dust was 10 to 30 times higher than in the other fractions.

The percent of radioactive material soluble in each case did not change significantly over a 4 to 5 month period. The radioactive decay rate for the suspended solids was similar to the rate for the soluble portion.

RADIOCHEMICAL ANALYSES OF SOIL AND WATER

The chief objective of this study was to determine if there is any large preferential dissolution of the internally hazardous radionuclides associated with fallout. The low level of activity in most of the samples made it necessary to work with large quantities of soil and this in turn complicated the chemical manipulations and counting. Thus it was not possible to get satisfactory results for all the individual radionuclides present. However, Table II does indicate that the dissolved solids contain about 5 times as much radioactive strontium as would be expected if all of the nuclides in the dry fallout material were equally soluble in water. In addition further fractionation of strontium usually occurs during the conventional water treatment process.

Table III shows the levels of activity of ideal fission product mixtures of various ages that would lead to a body burden of 5 μc of Sr^{90} if used for one year together with estimates of radiation doses to the gut and to the skeleton due to use of such water.

TABLE I

SOLUBILITY OF PRIMARY FALLOUT
NEVADA TEST, JUNE 24, 1957

Sample		Date Counted	Gross Beta Radioactivity in μμc/mg			Percent DS/ SS+DS
Size in μ	Source		Suspended Solids	Dissolved Solids	S.S. & DS	
< 5	30 yards from Gr. Zero	8/24/57	44.	4.9	48.9	10.
		10/24/57	24.	2.6	26.6	9.8
		12/24/57	18.	1.8	19.8	9.1
5 - 50	30 yards from Gr. Zero	8/24/57	39.	3.7	42.7	8.7
		10/24/57	24.	2.2	26.2	8.4
		12/24/57	16.5	1.5	18.0	8.3
> 50	30 yards from Gr. Zero	8/24/57	40.	4.4	44.4	9.9
		10/24/57	23.	2.3	25.3	9.1
		12/24/57	17.	1.6	18.6	8.6
< 5	4000 yards from Gr. Zero	7/24/57	400.	14.	414.	3.4
		8/24/57	170.	6.	176.	3.5
		10/24/57	69.	1.5	70.5	2.2
		11/24/57	48.	0.9	48.9	1.9
5 - 50	4000 yards from Gr. Zero	7/24/57	23.	4.0	27.0	12.
		8/24/57	10.	1.7	11.7	14.
		10/24/57	4.2	0.56	4.76	12.
		11/24/57	3.0	0.36	3.36	11.
> 50	4000 yards from Gr. Zero	7/24/57	11.	1.6	12.6	13.
		8/24/57	5.	0.75	5.75	13.
		10/24/57	2.1	0.30	2.40	12.
		11/24/57	1.5	0.20	1.70	12.

TABLE II

RELATIVE SOLUBILITY OF STRONTIUM IN WATER
NEVADA TEST SHOT, JUNE 24, 1957

Sample			Gross Beta in soil μμc/mg	Strontium in soil μμc/mg	Ratio$_1$= $\frac{G.B_{soil}}{Sr_{soil}}$	Gross Beta in Soluble Portion μμc/l	Strontium in Soluble Portion μμc/l	Ratio$_2$= $\frac{G.B._{water}}{Sr_{water}}$	Ratio$_3$= $\frac{Ratio_1}{Ratio_2}$
Size in μ	Source	Date							
< 5	30 yds. from Gr.Zero	4/21/58	22	0.11	200	2500	68	37	5.4
5-50	30 yds. from Gr.Zero	4/21/58	22	0.14	160	2100	70	30	5.3
> 50	30 yds. from Gr.Zero	4/21/58	19	0.18	110	1700	73	23	4.8

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TABLE III

GROSS FISSION PRODUCT ACTIVITY (μc/ml) AND DOSE (rep) TO GUT AND SKELETON AT VARIOUS TIMES

Age at Start of Use	Gross Fission Product Activity for 365 Day Comsumption*	Total Dose to Gut** for 365 Day Comsumption (All Fission Products)	Dose to Skeleton*** For 365 Day Consumption	
			Dose During 1st Yr.	Dose to Infinity
1 Day	1.1 μc/ml	750 rep	195 rep	675 rep
10 Days	7.0×10^{-2} μc/ml	500 rep	165 rep	650 rep
30 Days	2.0×10^{-2} μc/ml	335 rep	125 rep	600 rep
90 Days	5.0×10^{-3} μc/ml	185 rep	55 rep	550 rep
365 Days	9.5×10^{-4} μc/ml	70 rep	5 rep	500 rep

* Consumption for 365 days will accumulate a Sr^{90} body burden of 5.0 μc

** Dose from all fission products to large bowel (assumes no G.I. absorption)

*** Dose from Sr^{89}, Sr^{90}-Y^{90}, Sr^{91}-Y^{91}, Zr^{95}-Nb^{95}, Ba^{140}-La^{140}, and rare earths.

From these considerations it would appear that maximum permissible concentrations of radioactivity in drinking water under military emergency conditions might well be in the order of 0.1 to 1.0 μc/ml during the early period after attack and that at later times considerably lower levels should be permitted to guard against the accumulation of Sr^{90}.

Inasmuch as the Sr^{90} body burden is seriously considered as a limiting basis for ingestion, the indicated fractionation of strontium has some significance. It could mean, for instance, that if the present gross activity MPC value were 1.0 μc/ml for D + 1, then this gross value should be lowered 5 to 10 times or to 0.1 μc/ml, so the Sr^{90} body burden in one year would not exceed 5 μc.

No specialized equipment for the monitoring of low levels of contamination in water in the presence of high gamma ray background is in existence at the present time. However, discussions between the Corps of Engineers and the Signal Corps have indicated a probe type instrument which can be immersed into the water under examination might best be suitable to satisfy the present requirement.

No construction details for such an instrument have been worked out at this time, but it is possible to predict the performance and the limitations of this type of probe from basic considerations. It will probably be desirable to equip this instrument with two detectors, one of which is sensitive only to gamma radiation (from the water under examination and from background radiation); the other sensitive to the aforementioned gamma radiation plus the beta radiation from the water contamination. Special circuitry in the instrument provides for subtraction of the gamma only, from the gamma plus beta, resulting in a beta only indication. The beta background from the "surrounding" or ambient radiation can be neglected because it is completely shielded by the water into which the probe is immersed.

A brief calculation below shows that under these circumstances, it will be possible to measure contamination down to 10^{-4} μc/ml or even 10^{-5}μc/ml if no appreciable outer gamma background is present. A sensitive detector of the Geiger-Mueller or scintillation type should be used, but details are not critical. In the presence of a high gamma outer background, the sensitivity of the detector will be reduced. It is estimated that in an external field of 1 r/hr, contaminations down to 10^{-2} to 10^{-3} μc/ml will be measurable. In a field of 10 r/hr, contaminations down to 10^{-1} to 10^{-2}μc/ml are possible of measurement.

It is not believed that in the present state of the art a much greater sensitivity can be achieved by using other methods of monitoring at the point of interest. Methods of differentiation between different radioisotopes by purely physical means are so complicated that they need not be considered in this connection. Examination of water samples at rear locations with low radiation background; e.g. by boiling down of the water will of course lead to much higher sensitivities. All presently known radiac instruments measure only the gross dose rate. Chemical separation methods will have to be used if a detailed determination of special isotopes is proven to be necessary.

SAMPLE CALCULATION

It is assumed that an extended body of water is uniformly contaminated with C microcuries of activity per milliliter of water. The gamma ray dose rate will then be constant throughout the water in all points not too close to the surface and is given by:

(1)

$$\text{D. R.} = \int_0^\infty \oint \frac{FC}{r^2} e^{-\mu r} \, dr \, d\Omega = \frac{4\pi FC}{\mu}$$

D. R. = dose rate in mr/hr.

C = activity concentration in μc/ml.

μ = gamma ray absorption coefficient in cm^{-1}.

F = conversion factor from activity to dose rate.

F depends on the energy of the gamma radiation and the true absorption coefficient of air at this energy and is of the order of 5 for gamma radiation of 1 Mev. Since μ is of the order of 0.04 at this energy,

(2) $\text{D.R.} = 500\,\pi C$

which means a dose rate of about 1/6 r/hr for an activity concentration of 1 μc/ml. The beta dose rate which corresponds to this contamination is of the same order of magnitude as the gamma dose rate because the much larger absorption μ of the betas is compensated by a correspondingly larger specific ionization in the detector (larger F.).

If only the natural background is present, dose rates of less than 0.1 mr/hr can be easily detected with senstive detectors. This means, according to equation 2, that contamination of the order of 10^{-5} μc/ml should be detectable under these circumstances. The existence of strong additional gamma fields introduces the problem of measuring the beta radiation from the contaminated water as the small difference of two large readings. The higher minimum activities given in the text for specified gamma background levels are obtained if a beta dose rate equal to one or a few percent of the gamma dose rate are considered as measurable. Because of the absorption of gamma radiation of outside origin within the water, the accuracy of the activity determination increases with increasing depth of immersion of the probe.

DECONTAMINATION BY NATURAL AND CONVENTIONAL TREATMENT

Plain Settling

Table IV indicates that where settling takes place for 16 to 24 hours, there will be a 62 to 92 percent removal of the radioactive material. Hence, an open reservoir will serve as a good protective device in removing particulate matter. From other fallout studies at this Center, it appears that any radionuclides in rain or fallout on land will be 90 percent retained on vegetation or soil and 10 percent washed into surface supplies during normal runoff. This retention percentage is approximately the same for activity associated with either solids or liquid. Thus a sizeable fraction of fallout radioactivity would be removed before reaching a water treatment plant.

Coagulation

Supernates from the overnight settling process were coagulated with 20 mg/l of ferric chloride plus lime when necessary to adjust the pH, but the success of any chemical treatment was very poor, removals varying from 4 to 76 percent depending somewhat on the addition of lime. Based on previous experience with radioactivity in ionic form, this was to be expected. Complete softening with a lime-soda ash process or high pH, phosphate coagulation will usually do much better, especially on such radionuclides as strontium.

TABLE IV

REMOVAL OF RADIONUCLIDES FROM MIXTURE OF FALLOUT AND WATER BY SETTLING, COAGULATION AND FILTRATION NEVADA TEST SHOT, JUNE 24, 1957

Sample				Plain Sedimentation		Coagulation of Settled Water with 20 mg/1 of $FeCl_3$					Filtration of Raw Mixture by Membrane Filter	
Particle Size Microns	Source	Date Counted	Gross Beta Radio-activity µµc/1	Gross Beta Remaining µµc/1	Percent Removal	Gross Beta Remaining µµc/1	Initial pH	Lime added mg/1	Final pH	Percent Removal	Gross Beta Remaining µµc/1	Percent Removal
< 5	30 yds from Gr.Zero	9/24/57	71,000	27,000	62	23,000	8.3	--	7.1	15	7,000	90
5-50	30 yds from Gr.Zero	9/24/57	79,500	24,500	69	23,600	8.3	--	7.0	4	7,000	91
> 50	30 yds from Gr.Zero	9/24/57	67,000	33,000	64	28,000	8.4	--	7.3	15	6,100	89
< 5	4000 yds. from Gr.Zero	8/20/57	31,000	2,600	92	900	6.7	26	6.8	65	970	97
		2/24/58	4,000	(Re-run on remaining portion of sample)							110	97
5-50	4000 yds. from Gr.Zero	8/20/57	15,000	2,400	84	1,500	7.2	7	7.2	38	1,900	87
		2/24/58	2,400	(Re-run on remaining portion of sample)							200	92
> 50	4000 yds. from Gr.Zero	8/20/57	14,000	3,800	73	900	7.8	7	7.8	76	2,000	86
		2/24/58	2,700	(Re-run on remaining portion of sample)							140	94

Filtration

By using a membrane filter, it was possible to remove all suspended material from a mixture of fallout and water. A conventional sand filter would be somewhat less efficient so filter plants could not hope to remove much more than 85 to 90 percent of the activity.

When combined serially, the normal water treatment processes will remove most of the radioactive particles, but only about 10 to 70 percent of the dissolved radionuclides.

Ion-exchange resins can be used to reduce the dissolved material by 99 percent. Since extensive research had been done previously on the efficacy of ion-exchange resins for removing radioactivity, no further tests were made during this project.

APPENDIX B

The Effect of Free Available Chlorine and Chlorine Dioxide upon Shellfish Poison (Aqueous) at pH 7.0 and 25°C.

by

A. R. Brazis, A. R. Bryant, P. Kabler, and R. L. Woodward

INTRODUCTION

Shellfish poisoning has been recognized as a problem for many years along the eastern and western coastlines of the United States and Canada. Although the poison is not harmful to shellfish, only a few milligrams are fatal to man.

There is no known antidote for shellfish poisoning. It is not affected by ultraviolet irradiation. When the poison in acid solution was held at 100°C. and treated with hydrogen peroxide, there was instantaneous inactivation. The poison is not adsorbed on aluminum hydroxide at different pH levels. Common sea sand, free from electrolytes, adsorbed approximately 90 percent of the poison from aqueous solution and little or none from an alcoholic solution. In aqueous solution, exposure to pH 6.6 and 11.5 for six days resulted in 35 and 74 percent loss in toxicity, respectively. Little is known concerning its resistance to disinfectants.

METHODOLOGY

The resistance of the shellfish poison has been evaluated in the presence of chlorine dioxide and free available chlorine at pH 7.0 and storage at 25° C. for two hours. Five hundred ml aliquots of the poison have been exposed to 2.0 mg/l chlorine dioxide, at concentrations of 4.7 and 47 micrograms (μg) per ml of solution. Equal aliquots of the poison have also been exposed to free available chlorine.

Measurement of the toxicity of the poison was made using the mouse bioassay method based on median death times of 5-7 minutes. Dilutions of the poison were necessary to induce death in White Swiss mice, weighing 19-21 grams, so as to occur within the designated death times. At the time of mouse inoculation, the poison was adjusted to pH 3.0. The poison used during this study was thought to be chemically pure.

Determinations of the chlorine dioxide and free available chlorine concentration and preparation of the buffered test water were the same as those used during an investigation concerning the resistance of Clostridium botulinum toxins. During this investigation, the buffer capacity and neutralizer (sodium thiosulfate) concentration were decreased to produce a neglibible salt effect upon the stability of the poison.

A buffer concentration of 0.01 molar and neutralizer concentration of 0.04 percent did not affect the toxicity of the poison under the conditions of the study.

Intervals of sampling were 15, 30, 60, and 120 minutes of exposure to either chlorine dioxide or free available chlorine. Samples were collected and placed in neutralizer, adjusted to pH 3.0, and inoculated into mice the following day. Control samples were handled similarly.

RESULTS

Exposure of 4.7 mg/l shellfish poison to 2.0 mg/l chlorine dioxide, added initially, at pH 7.0 and 25°C., produced greater than 93 percent inactivation of the poison within 2 hours. Under the conditions of the investigation, reduction of toxicity of the poison was based on the number of mouse units present per ml of test water. One mouse unit was equal to 0.183 micrograms of poison.

When the poison concentration was increased to 263 mouse units per ml. (47 mg/l) the toxicity of the poison was not affected by 2 mg/l of chlorine dioxide.

When 2.0 mg/l free available chlorine were added initially to 26 mouse units/ml (4.7 mg/l) of the poison, there was no reduction of the toxicity of the poison. During this examination, the free available chlorine concentration decreased from 2.0 mg/l to less than 0.05 mg/l during the first 3½ minutes of exposure to the poison. At the end of two hours, there were 1.5 mg/l combined chlorine in the test water. Since it is acknowledged that the poison constitutes some type of nitrogenous base, it is most probable that the free available chlorine was instantaneously changed in its chemical nature, when added to the poison.

During the utliization of chlorine dioxide, in the presence of 4.7 mg/l of poison, the concentration decreased from 1.9 mg/l to 1.24 mg/l during the first 3½ minutes and to 0.73 mg/l at the end of 2 hours.

SUMMARY

The shellfish poison in aqueous solution was exposed to chlorine dioxide and free available chlorine at pH 7.0 and stored at 25°C. for 2 hours. Of the two disinfectants used, only chlorine dioxide inactivated the poison, and this effect only occurred using a low concentration of the poison (4.7 mg/l). When the concentration of poison was increased to 47 mg/l, 2.0 mg/l chlorine dioxide produced little or no inactivation. This work must be looked upon as exploratory only and further investigations are needed to define the usefulness of chlorine and chlorine dioxide in destroying shellfish poison. The lack of an adequate supply of the poison made further work impossible.

APPENDIX C

Activated Carbon Experiments

I. Dechlorination with Granular Activated Carbon Beds

by

F. M. Crompton, W. K. Muschler, and R. L. Woodward

Five small filters were used to test the practicability of dechlorinating water with granular activated carbon. They were constructed of lucite plastic columns 1 inch in diameter and 6 feet long, and were filled with 30 inches of activated carbon. Four different carbons were tested; one was used in two columns.

1. Cliffchar Carbon (granular)
2. Pitt Carbon (10 x 30 mesh)
3. Pitt Carbon (20 x 40 mesh)
4. Hydrodarco Carbon (finer of the two grades available)

Water averaging about 20 ppm free available chlorine was run through the carbon filters at a rate equivalent to 3 gallons per square foot per minute. The tests were started in September, 1956 and continued until early January, 1957 or until a carbon column became clogged, whichever came first. When necessary the columns were backwashed using Cincinnati tap water.

A summary of results are shown in the following table:

TABLE I

Carbon	Initial Vol. (cu. inches)	Final Vol. (cu. inches)	Free Chlorine Removed (grams)	Free Chlorine Removed per in^3 Carbon (grams)
Hydrodarco Tube I	30	27.6	51.6	1.87
Hydrodarco Tube 2	30	23.2	95.2	4.12
Pitt 10 x 30	30	26.9	128.9	4.78
Pitt 20 x 40	30	24.9	61.1	2.45
Cliffchar	30	25.9	116.3	4.50

The dechlorinating ability of all of the carbons tested was judged to be satisfactory for practical application in a carbon filter. On the basis of results for Pitt 10 x 30 carbon, the most nearly depleted when the test was stopped, it may be estimated that a filter bed 30 inches deep will dechlorinate water having a 15 ppm free chlorine residual for at least 6 months. Sometime after this replacement will be necessary. When the chlorine residual is less, the life of the carbon will be correspondingly greater.

Over the range of flow and influent chlorine concentrations tested, the filter effluent chlorine residual was approximately constant for each type of carbon. The highest residual, in the range of 0.1 ppm was obtained from Pitt 10 x 30 carbon. The effluent residuals for other carbons were less, usually between 0.1 and 0.04 ppm. Some effluent residual is desirable.

Head loss characteristics and clogging problems are of paramount importance to practical operation of a carbon filter. These tests showed that they are the most important criteria for selecting a suitable granular carbon for dechlorination. A coarse carbon is recommended to minimize head loss. A carbon should be dense, as well, since a dense carbon permits more rapid backwash rates and results in better cleaning.

A good deal of trouble from "washing over" light carbons was experienced in backwashing during the tests. This is demonstrated in Table I by comparing the final carbon volumes to the initial volumes.

Pitt 10 x 30 was the most coarse and dense carbon tested. For practical operation in a carbon filter, Pitt 10 x 30 would likely give very satisfactory service.

During the last month of operation, samples were collected for bacteriological examination from the three columns still in operation. The samples were plated on Tryptose Glucose Extract agar and incubated at 20° for periods up to 72 hours. The results showed that some bacteria do grow in the carbon columns but a test for coliform bacteria was negative. While these growths have no health significance they are troublesome and may be responsible for clogging. Provision must be made to eliminate them periodically, preferably by steaming the carbon bed.

APPENDIX C

Activated Carbon Experiments

II. Removal of Clostridium botulinum Type A Toxin from Water by Passage Through Activated Carbon

by

A. R. Brazis, A. R. Bryant, P. Kabler, and R. L. Woodward

INTRODUCTION

The objectives of this exploratory investigation were as follows:

1. To determine if botulinum toxin is removed from water during passage through the activated carbon column.
2. To obtain data on the efficiency of the carbon during long and short periods of loading.

METHODOLOGY

The carbon used in this study was produced by the Pittsburgh Coke and Chemical Company with the nomenclature: type "GW", 10 x 30 mesh.

The carbon was placed in a 25 ml burette thus making a filter of the following characteristics:

Weight of carbon added	5.1810 grams
Volume of Carbon	11.0 ml
Diameter of column	0.971 cm.
Height of column	15.2 cm.
Area of column	0.74 cm^2
Flow rate	9.03 mg/min or 11.1 min/100 ml

The carbon column was continuously dosed with the type A toxin during two brief experiments.

RESULTS

In experiment #1, a stock strength of the type "A" toxin containing 4,500 mouse LD_{50}s per ml of solution was used. A total of 2,000 ml, at pH 7.0 and 25°C., was applied to the column during a period of $3\frac{1}{2}$ hours. Samples were collected in 100 ml aliquots every eleven minutes. At the end of approximately one hour of filtration, 90 to 98 percent of the toxin was removed. See Figure 1. At the end of approximately three hours, 42 percent of the toxin being dosed was passing through the filter unaffected.

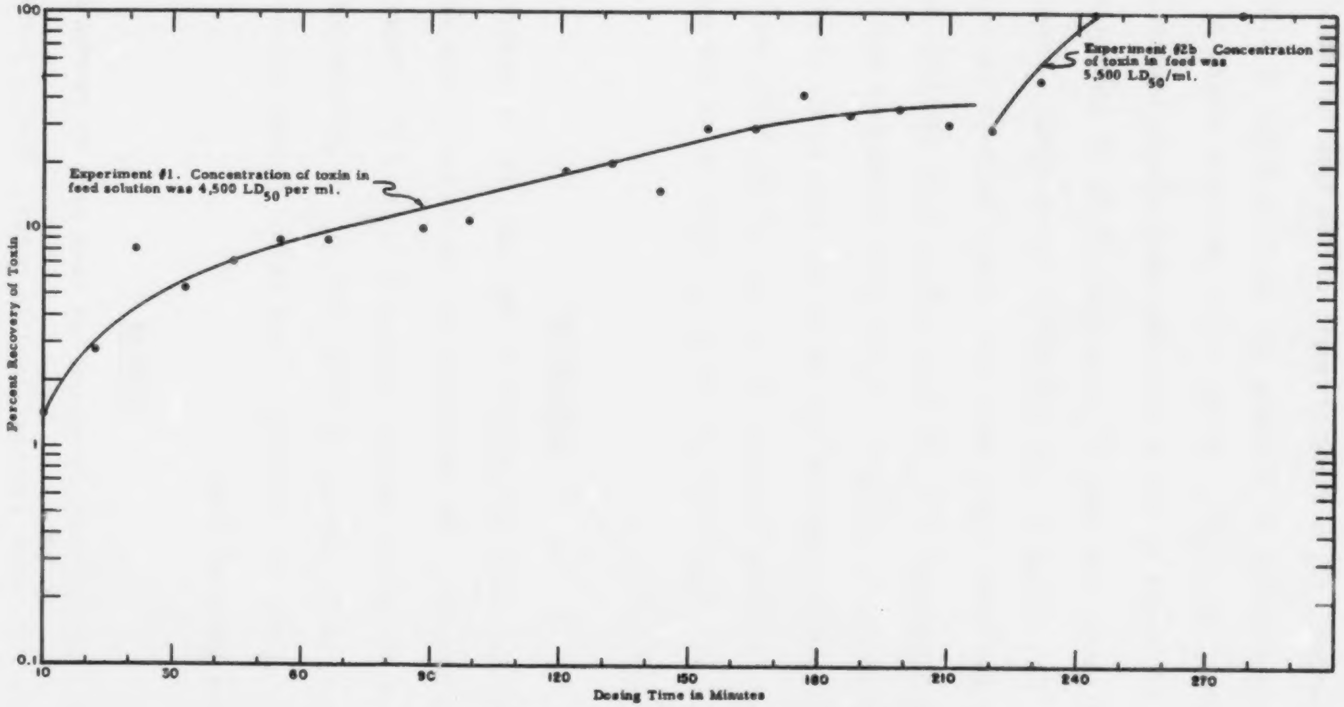
During Experiment #2b, the same column which had been used in Experiment #1 was utilized, after it had been backwashed with distilled water. The type "A" toxin was applied at the same rate. During the first eleven minutes of carbon passage, 71 percent of the toxin was removed. However, during the next hour and three-quarters, 99 to 100 percent of the toxin passed through.

DISCUSSION

It appeared that the removal of the toxin by the carbon was adsorptive in character. The efficiency of the carbon column during prolonged periods of dosing was low, following loss of its adsorptive capacity during early periods of toxin dosing. No conclusions were drawn concerning the low capacity of the carbon column following early removal of the type "A" toxin.

SUMMARY

A small compact carbon column has been used to remove Clostridium botulinum type "A" toxin (crystalline) in water. Dosing periods ranged from 2 to 4 hours. Using activated carbon, the toxin was removed, appar-



REMOVAL OF CLOSTRIDIUM BOTULINUM TYPE "A" TOXIN FROM WATER BY FILTRATION THROUGH PITTSBURGH CARBON TYPE "GW" 10 x 30 MESH

Figure 1

ently by adsorption, by 90 to 98 percent during the first hour of treatment. Continued dosing appeared to reduce the efficiency to 42 percent at the end of three hours. Backwashing of the carbon did not appear to increase, significantly, the efficiency of the carbon. Further loading of the column produced 99 to 100 percent persistence of the toxin within 30 minutes following backwashing.

The carbon column appeared to reach its adsorptive capacity within a short period of time. It seemed likely that further studies using greater depths of activated carbon, different types of carbon, and lower concentrations of toxin may be necessary to judge the effectiveness of the carbon column with regard to removal of bacterial toxins.

APPENDIX C

Activated Carbon Experiments

III. Use of Carbon for Removal of GB From Water

by

Jesse M. Cohen and F. M. Crompton

INTRODUCTION

Active carbon has been recommended by several investigators for removal of toxic war gases from water. Data are available in the literature on the capacity of various carbons for removing the organic phosphate class of war gases, called "nerve" gas, from water. These reports concluded that several carbons were effective adsorbents, in reasonable concentrations, for removing toxic concentrations of GB from water. Since previous work covered only batch treatment of water by carbons in powdered form and, since the carbons tested did not include the carbons under consideration for chlorine removal, it was necessary for this laboratory to obtain additional information.

The objectives of this brief study were to:

1. Obtain data for the construction of an adsorption isotherm to enable a comparison of the carbon under study with carbons previously investigated.
2. Determine whether removal of GB from water is feasible by a column process in contrast to the previously reported batch operation.

EXPERIMENTAL

BATCH TREATMENT

Batch treatment of water contaminated with GB with varying amounts of carbon was performed in the usual manner for determining adsorption isotherms for carbon. Some of the conditions of the test were based on previous experience in the literature. Other conditions were arbitrary or dictated by the use of the carbon in practice.

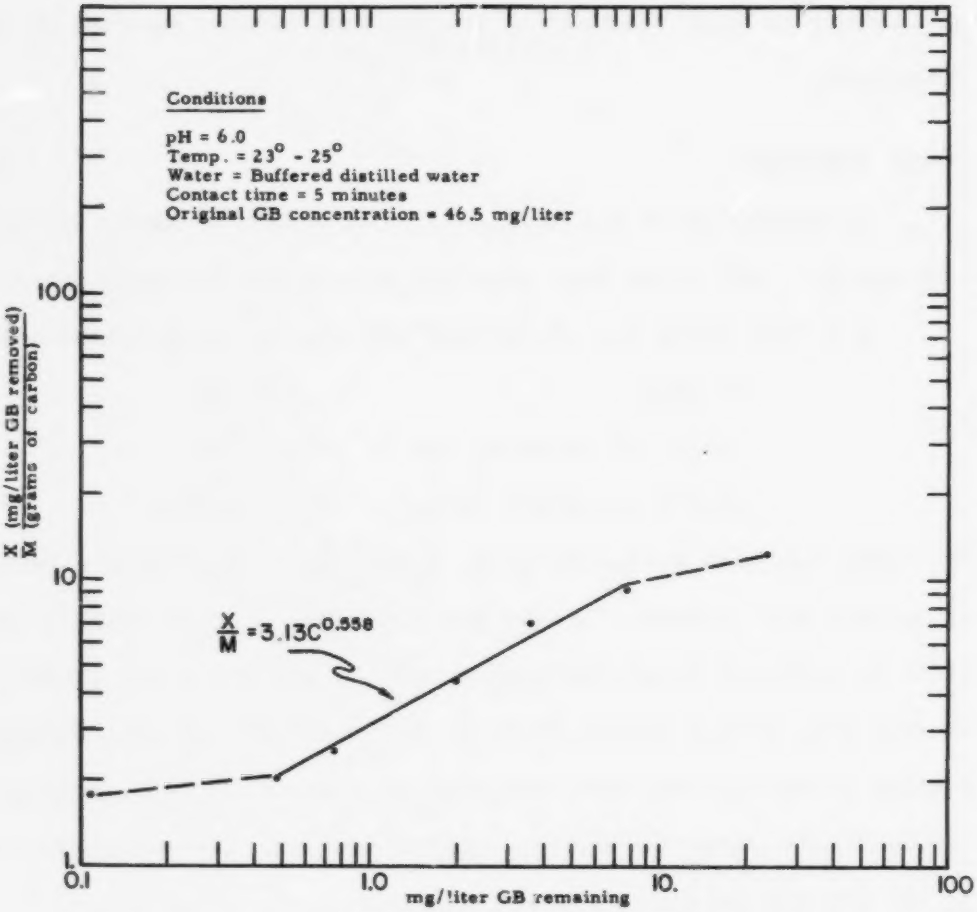
Seven 200 ml portions of distilled water, buffered at pH 6.0 and containing about 50 ppm of GB, were treated with varying amounts of carbon. The solutions containing suspended carbon were agitated with an efficient wrist-action shaker for five minutes. The usual stirrer type of mixing could not be used in these experiments because the granular form and high density of the carbon prevented dispersion of the suspension. The method used provided a satisfactory dispersion. At the end of the shaking period, suspended carbon was removed by filtration through medium porosity fritted glass filters. Analyses for GB remaining in the filtrate were performed immediately by the peroxide procedure which is specific for GB. Buffered water at pH 6.0 was chosen to minimize hydrolysis of GB. A five-minute contact time was chosen since this corresponded approximately to the detention time in a column operation with a loading of 3 gal/ft^2/min. The data obtained in this experiment are shown in Table I. Also shown are the data for construction of the adsorption isotherm for this test. The latter data were computed according to the empirical adsorption equation of Freundlich and are plotted on double logarithmic paper in Figure 1. The equation for the straight portion of the line is calculated to be:

$$\frac{X}{M} = 3.13\ C^{0.558}$$

TABLE I

REMOVAL OF GB FROM WATER BY PITTSBURGH CARBON TYPE "GW" 10 x 30 MESH

Carbon added in grams	Solution in ml	GB in mg/liter			$\frac{X}{M}$	Percent GB Removed
		Before "C_o"	After "C"	Removed $X(C_o-C)$		
0.0	200	46.5	--	--		
2.03	200	46.5	23.5	23.0	11.3	49.5
4.17	200	46.5	7.7	38.8	9.30	83.5
6.11	200	46.5	3.6	42.9	7.02	92.3
10.0	200	46.5	2.0	44.5	4.45	95.7
18.3	200	46.5	0.76	45.74	2.50	98.4
22.1	200	46.5	0.48	46.02	2.08	99.0
26.2	200	46.5	0.11	46.39	1.77	99.9



REMOVAL OF G.B. FROM WATER
BY PITTSBURGH CARBON TYPE "GW"
10 x 30 MESH

Figure 1

Two points not on this line can be ascribed to analytical difficulties in determining accurately small amounts of GB.

The data show that the carbon under test does not compare favorably with carbons reported in the literature. This, however, may merely reflect the fact that this carbon is a granular material and hence not as efficient an adsorber in batch treatment as the powdered carbons reported in the literature.

COLUMN TREATMENT

Determination of the capacity of this carbon to remove GB from water solution on a continuous flow basis was made in the following manner.

A carbon filter was constructed with the following specifications:

Diameter	2.94	cm
Height of carbon column	31.4	cm
Weight of air-dry carbon	105.	grms.

By backwashing with distilled water, carbon fines and soluble alkaline salts were first removed. A feed solution, 9955 ml, containing 57 mg/l of GB in distilled water, buffered at pH 6.0, was fed to the column at an average rate of 62.1 ml/min, which is equivalent to 2.25 gal/ft^2/min. Samples of the effluent were collected in separate aliquots, ranging from 100 to 500 ml, over the entire period of the run. Determinations for GB in the effluent were made within 2 hours of sample collection.

No GB was detected in any of the filtrate samples, which leads to the conclusion that a minimum of 567 mg of GB put on the filter was removed by 105 gram of carbon or at least 54 mg of GB/gram of carbon.

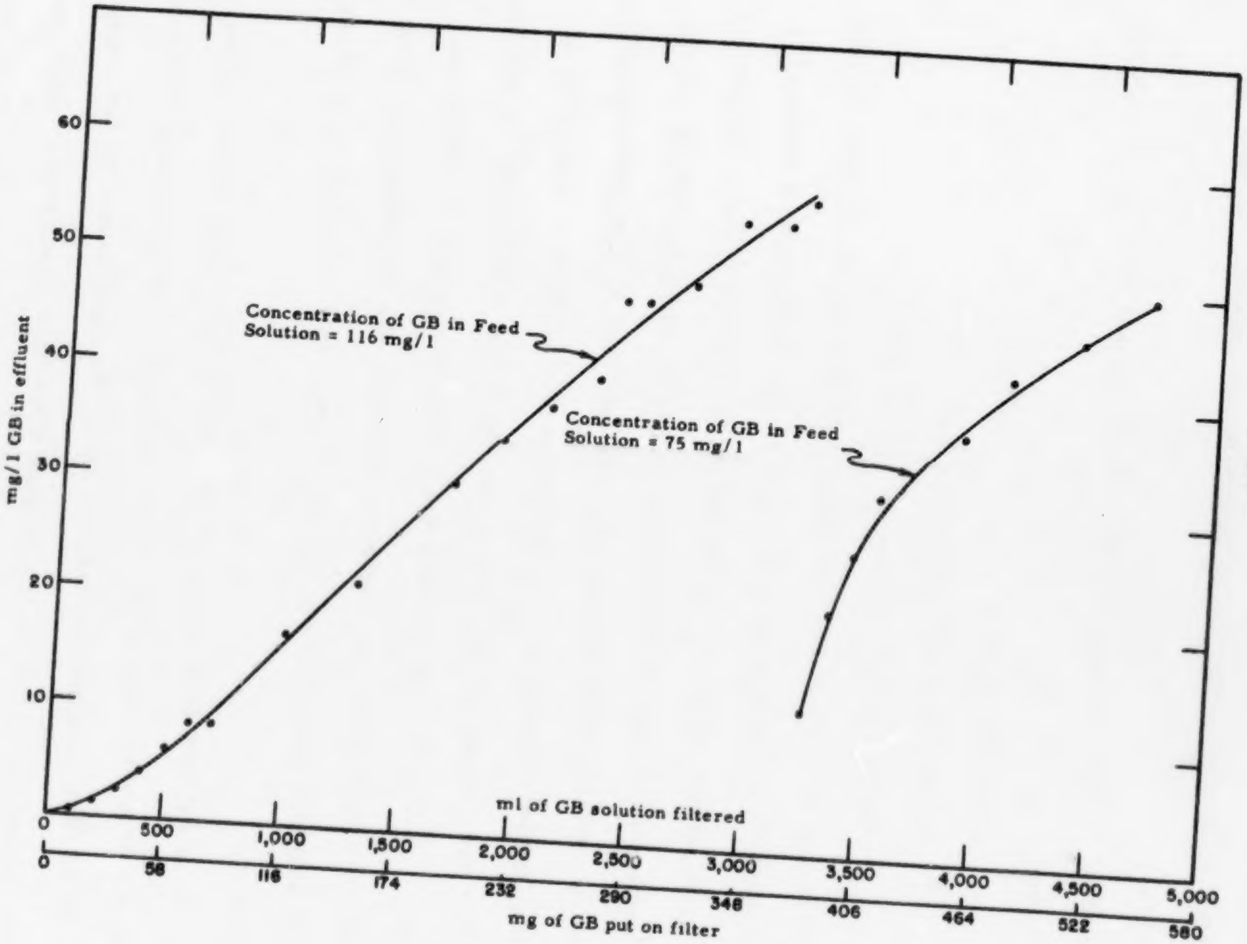
Because of the limited supply of GB, the large column was abandoned and a smaller filter was operated to determine the capacity of this carbon for GB removal.

A carbon filter was prepared in a 25 ml burette with the following specifications:

Diameter	0.971 cm.
Height of carbon column	15.2 cm.
Weight of air dry carbon	5.21 grm.

Operation of this column was similar to the larger filter. A feed solution containing 116 ppm of GB was fed to the filter at an average rate of 9.06 mg/min, which is equivalent to 2.33 gal/ft^2/min. Samples of the effluent were collected in separate aliquots, ranging from 50 to 100 ml, over the entire period of the run. In contrast to the previous filter, increasing concentrations of GB appeared in the filtrate. Operation of the filter was stopped at the end of the day's run after 3,200 ml had been collected. Filtration was resumed the following day and an additional 1,600 ml were collected. On standing overnight the concentration of GB in the feed solution dropped from 116 to 75 ppm. This information is shown in Figure 2.

It is evident from these curves that the capacity of the carbon column was exceeded very early in the operation, and increasing concentrations of GB were obtained in the effluent. No conclusions on the capacity of this carbon to remove GB can be made from this experiment. Comparison of the data on the two columns suggest that the depth of the carbon column has a profound influence on the capacity to remove GB.



REMOVAL OF GB FROM WATER BY
FILTRATION THROUGH PITTSBURGH CARBON
TYPE "GW" 10 x 30 MESH

Figure 2

The curve showing data obtained after resting the column overnight indicates that adsorption may not be the entire mechanism for GB removal. The greatly lowered initial concentrations of GB in the effluent would suggest that the carbon catalytically increased the rate of GB hydrolysis. Further evidence in support of this hypothesis is the fact that increasing amounts of fluoride were detected in the effluents from the larger column, as follows:

Determination of Fluoride in Filtrate

Aliquot at indicated vol. of solution filtered	mg/liter Fluoride in filtrate	Percent GB Hydrolyzed
200 ml	1.2	16
5000 ml	1.6	21
9500 ml	2.4	31

SUMMARY

1. Data was obtained for the construction of an adsorption isotherm for carbon removal of GB from water.
2. One column experiment operated on a continuous flow basis showed that a minimum of 5.4 mg GB/grm carbon could be removed from solution on a column 31.4 cm in depth.
3. Capacity of a second, smaller column, 15.2 cm in depth, was exceeded very early in the experiment and increasing concentrations of GB were obtained in the filtrate.
4. Mechanism of GB removal may include catalytic hydrolysis in addition to adsorption.
5. Removal of GB from water by a column operation was more effective than would have been predicted from the adsorption isotherm data.

APPENDIX D

Design of Gravel Filled Chlorine Contact Tank

by

F. M. Crompton, W. K. Muschler and R. L. Woodward

INTRODUCTION

The purpose of a chlorine contact tank is to retain chlorinated water for a time sufficient to insure destruction of any microorganisms present before the water reaches a point of use. The tests reported here show that a tank filled with a granular media, pea gravel in this case, is a practical way to provide chlorine contact.

A chlorine contact tank should have the following characteristics:

1. It should minimize short-circuiting of the flow.
2. It should have stable flow pattern over the range of expected flows and temperature fluctuations.
3. It should be economical to construct and maintain.

In these investigations the retention characteristics of tanks were determined by injecting a dye tracer into the influent water and detecting the dye in the effluent from the tank. For approximate comparisons of various arrangements, the time of appearance of the first trace of dye was used. For more thorough studies complete curves of dye concentration as a function of time were defined. The ratio of first trace time to the theoretical displacement time of the tank gives a measure of the effectiveness of the tank as a chlorine contact chamber.

Before considering flow through granular media as a method of chlorine contact, flow through unbaffled cylindrical tanks was investigated because of the obvious simplicity and low cost of such tanks.

Both horizontal and vertical flow arrangements were studied, but in all such tanks, poor results were obtained. Short circuiting was pronounced and the flow patterns were markedly unstable. Variations in rate of flow and minor temperature changes in the water caused major changes in the retention characteristics of such tanks even though great care was taken in design of the inlet to obtain even distribution across the section of the tank. In the tanks studied, the ratio of first trace time to theoretical flow-through time was highly variable and generally less than 0.2.

One vertical baffling arrangement studied was found to have a first trace time consistently greater than 0.4 of the average flow-through time, and a stable flow pattern as well. This arrangement consists of concentric cylinders, each with one open end, placed vertically with the open ends alternately at the top and bottom of the tank. The flow path begins at the outside and converges inward through the over-and-under arrangement. While the performance of a model of this type tank is excellent, construction costs would be relatively high.

The device recommended here consists of a vertical-flow tank filled with pea gravel. Horizontal flow is not practical for obvious reasons. A gravel-filled tank has an advantage of being simple and economical to construct.

TEST SET-UP

To test the flow-through characteristics of a tank filled with a granular media, two experimental set-ups were devised.

Preliminary tests were conducted using a 55-gallon steel drum, shown in Figure 1, filled with pea gravel, effective size = 0.13 inch and uniformity coefficient = 1.75. Two flow rates were used, 0.25 and 0.75 gpm; the resulting mean velocities through the voids were 0.0021 and 0.0063 ft/sec, respectively.

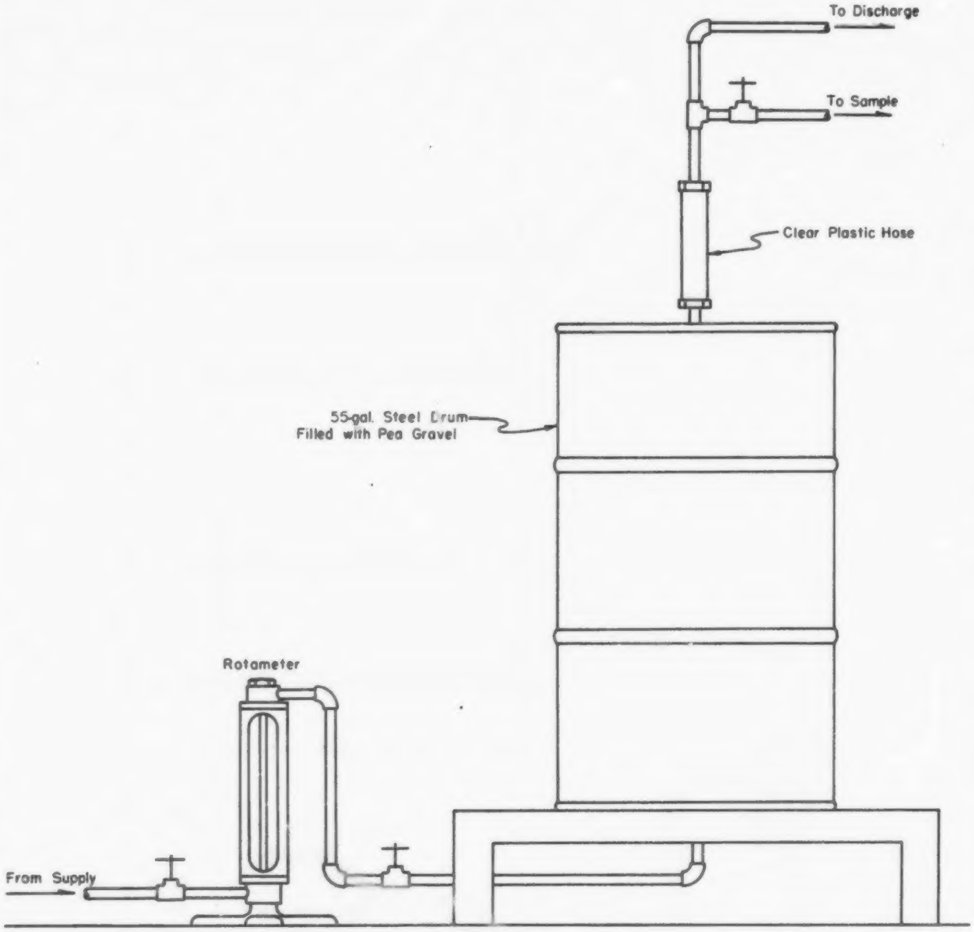
Results using the 55-gallon steel drum showed that the method held promise and a full depth set-up should be tested. Figure 2 shows the cylindrical tank assembled for this purpose. The tank was filled with 15 feet of pea gravel, having an effective size of 0.137 inch and a uniformity coefficient of 1.97. The gravel was supported by five grates as shown in the figure. For an inlet distribution system, a 4-inch clear space was provided below the gravel fill. Metered flow was piped into opposite sides of this space. The outlet arrangement was the same as the inlet distribution system. The large scale set-up was tested at three flow rates; namely, 2.65, 10.6, and 30 gpm. These resulted in mean velocities through the voids of 0.0021, 0.0082, and 0.023 ft/sec, respectively.

Fluorescein dye was used as the flow tracer. A concentrated solution (586.5 mg/ml) was injected into the flow, using a hypodermic needle and a syringe just after passing the metering device.

In both test set-ups, the flow was sampled at intervals from a tee in the effluent line. The optical density of the sample was determined on a Model 20, Bausch and Lomb Colorimeter, using a wave length of 495 mμ.

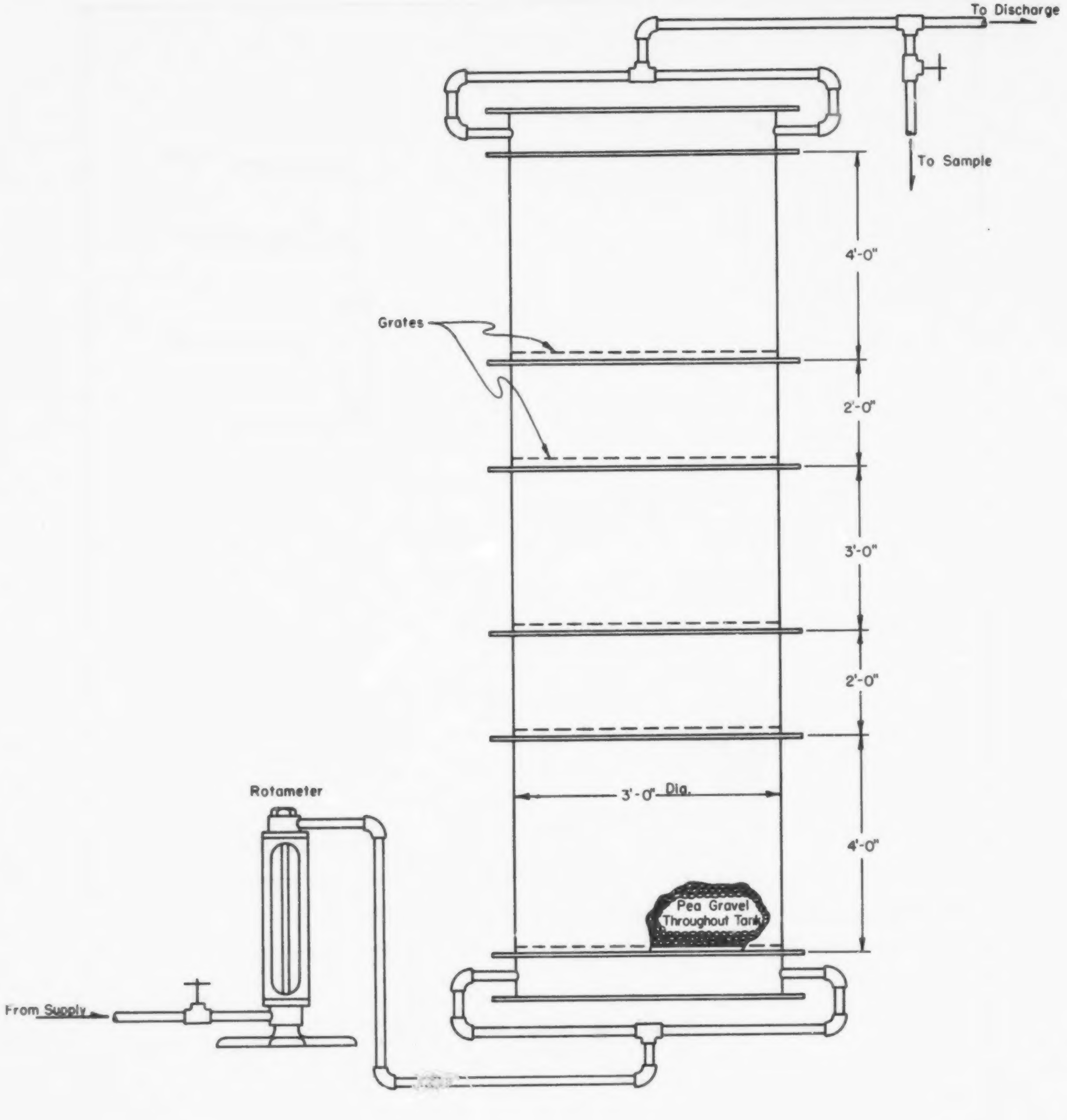
RESULTS

Figures 3 and 4 show the flow-through curves obtained in the 55- gallon steel drums at the two flow rates tested. Figures 5, 6, and 7 show the flow-through curves obtained at different flow rates in the 15-foot gravel filled tank.


To Discharge
To Sample
Clear Plastic Hose
55-gal. Steel Drum Filled with Pea Gravel
Rotameter
From Supply

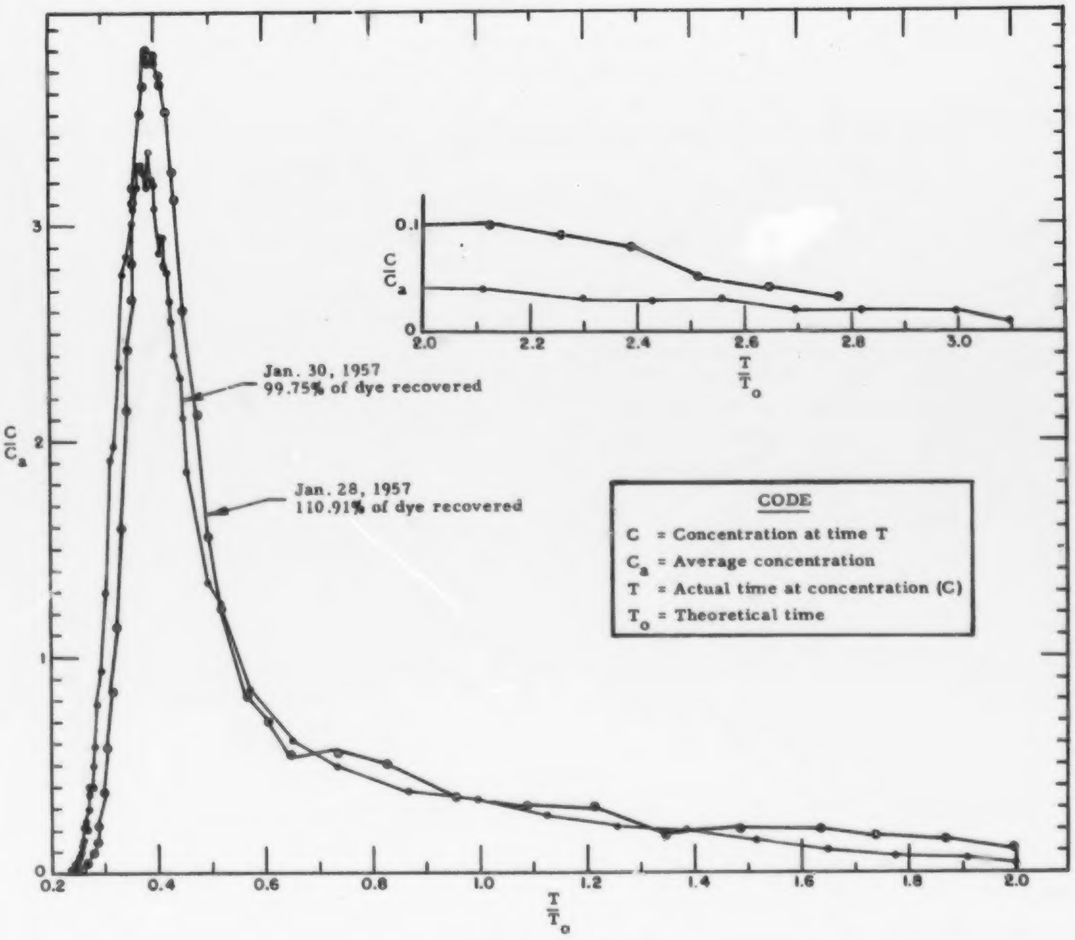
55-GALLON CHLORINE CONTACT TANK

Figure I


To Discharge
To Sample
4'-0"
Grates
2'-0"
3'-0"
2'-0"
Rotameter
3'-0" Dia.
4'-0"
Pea Gravel Throughout Tank
From Supply

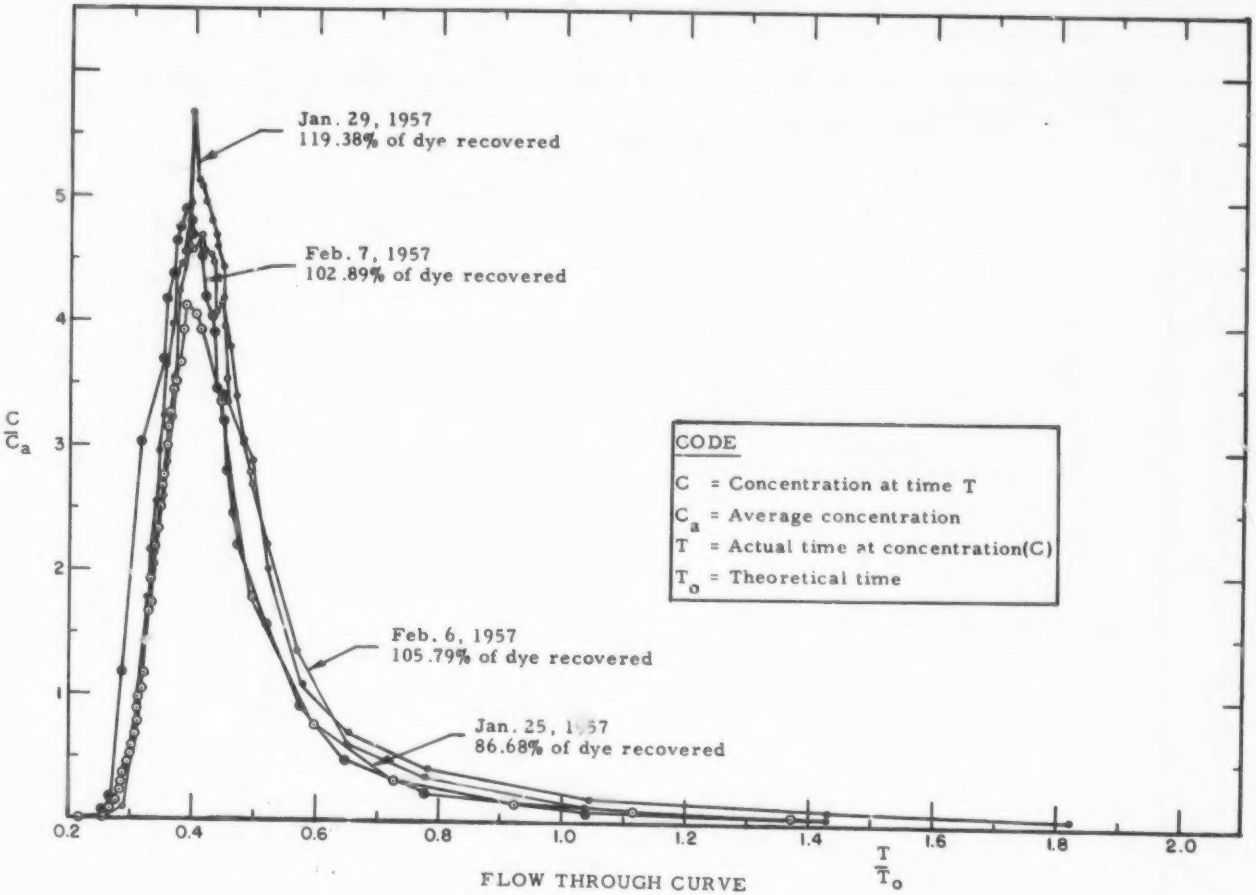
15-Foot CHLORINE CONTACT TANK

Figure 2

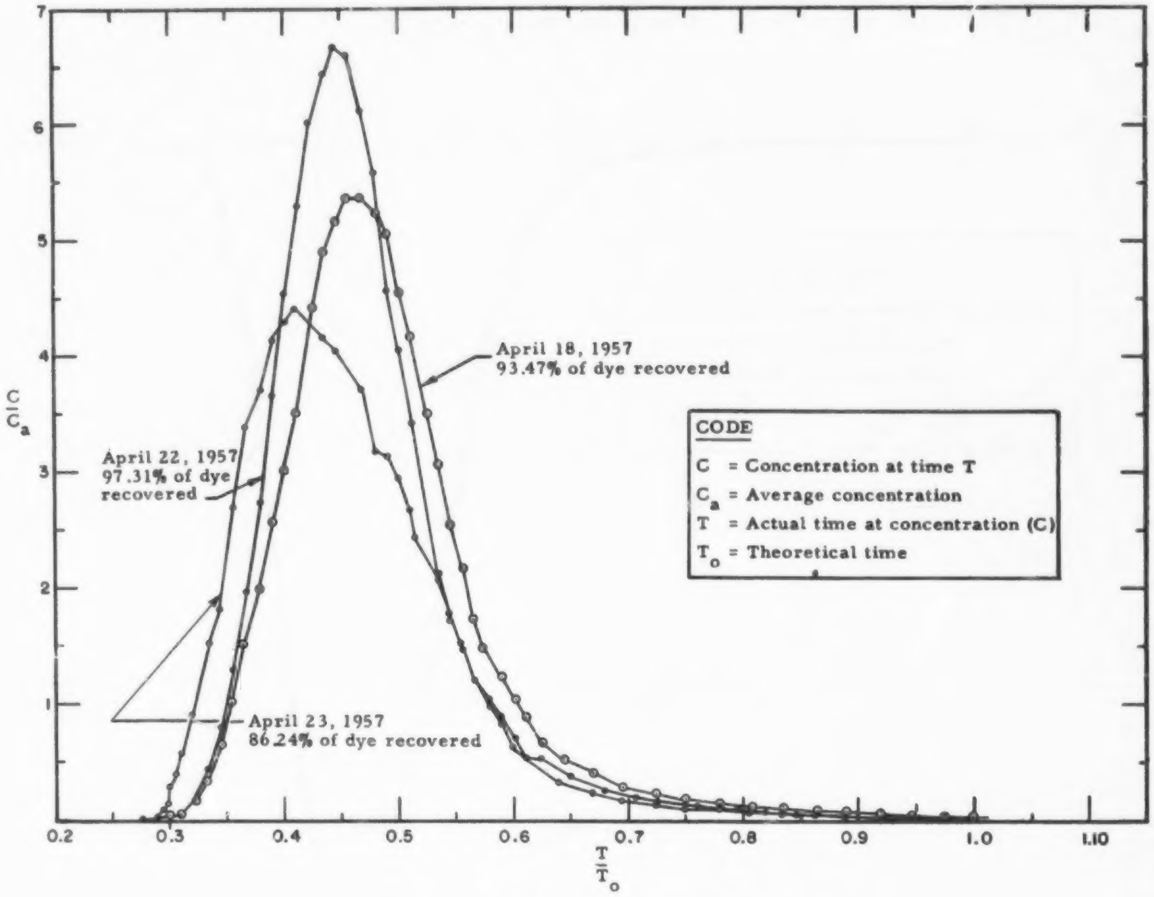


FLOW THROUGH CURVE
55-GALLON TANK AT 0.25 GPM

Figure 3

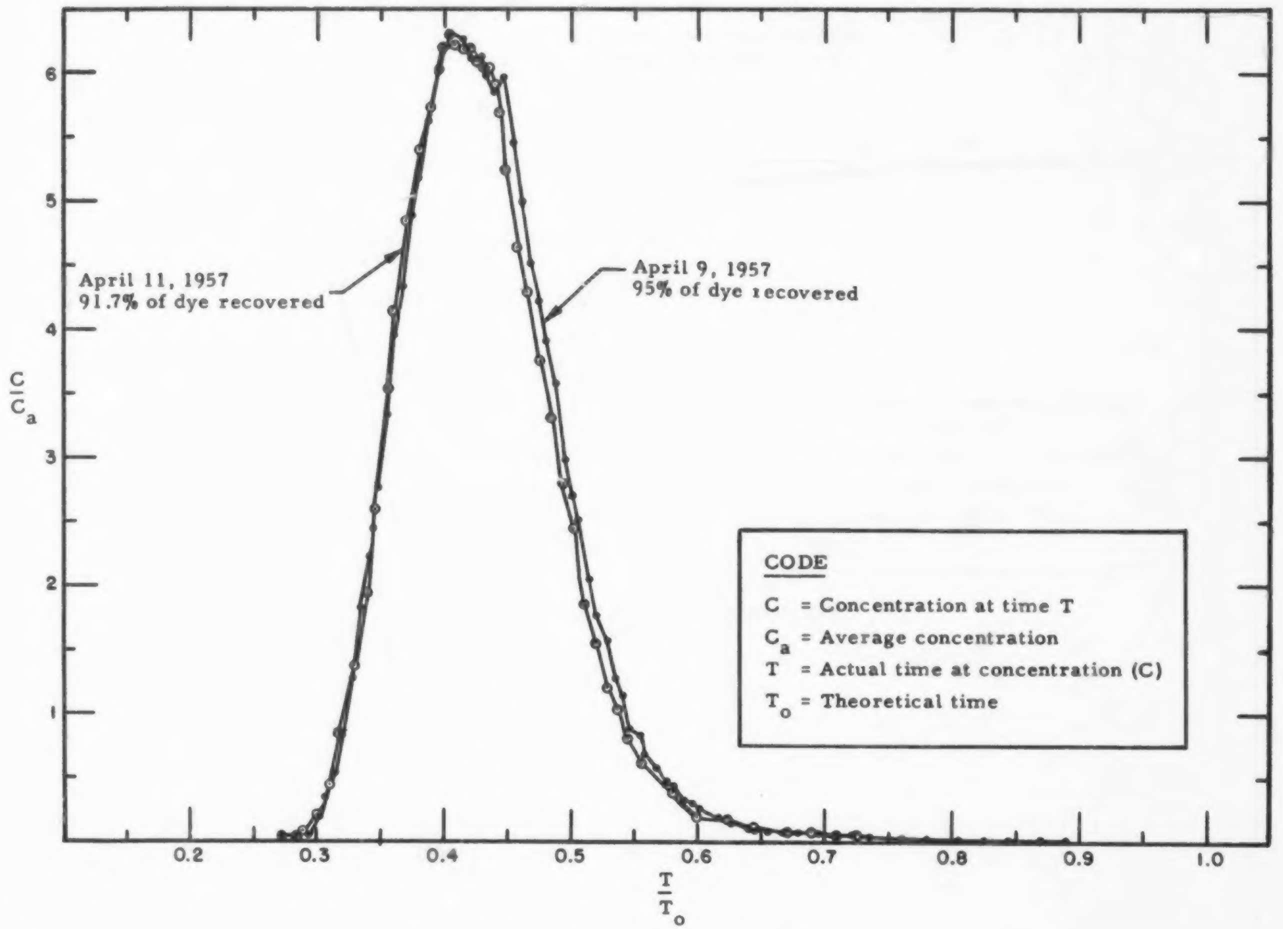


FLOW THROUGH CURVE
55-gallon tank at 0.75 G. P. M.
FIGURE 4



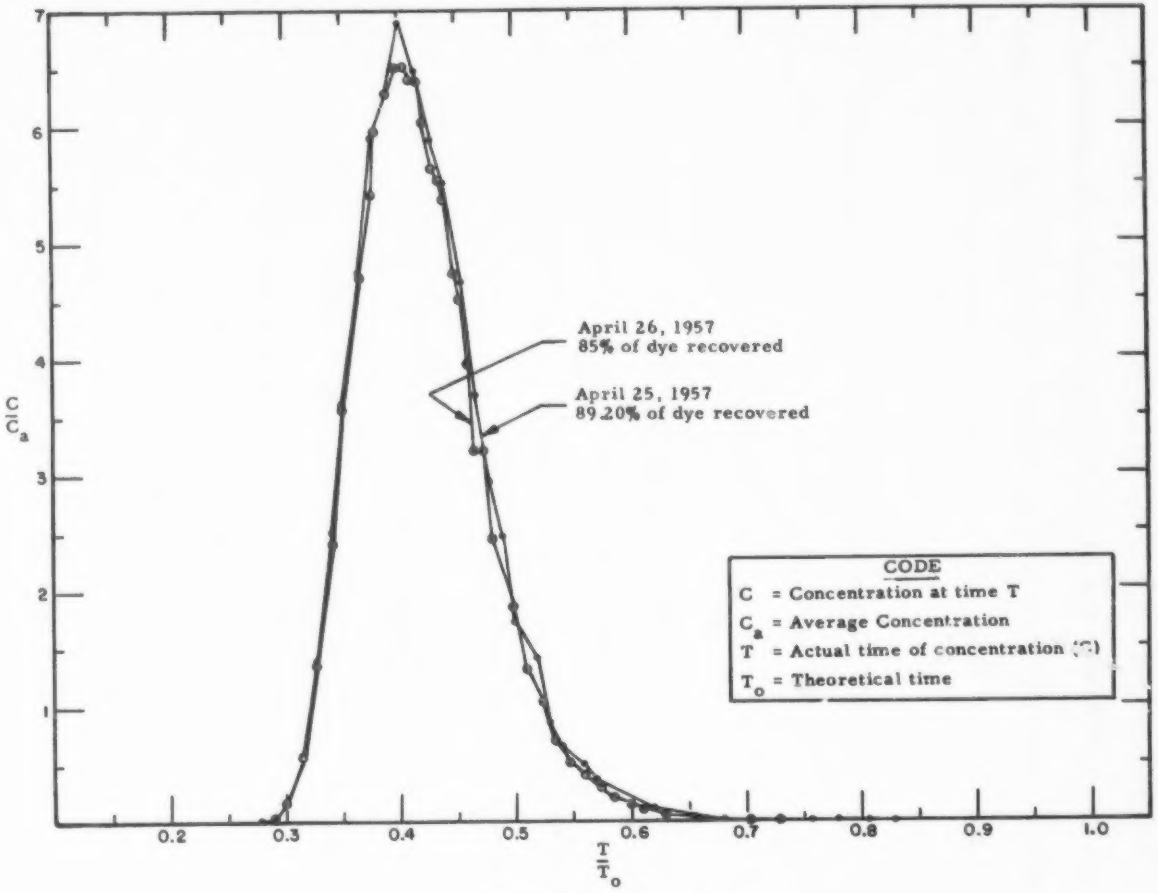
FLOW THROUGH CURVE
15-FOOT TANK AT 2.65 GPM

Figure 5



FLOW THROUGH CURVE
15-FOOT TANK AT 10.6 GPM

Figure 6



FLOW THROUGH CURVE
15-FOOT TANK AT 30 GPM

Figure 7

The ordinates of the flow-through curves have been obtained by dividing each observed dye concentration (C) by the concentration (C_o) that would have been obtained if the dye used had been evenly dispersed in the gross tank volume (volume without gravel fill). The abscissa were obtained by dividing the time (T) of an observed concentration by a theoretical flow-through time (T_o) calculated by dividing the gross tank volume by the rate of flow. In this manner, a dimensionless plot is obtained.

The flow-through curves demonstrate that the flow pattern was extremely stable. Temperature differences of 5°C in the incoming water did not upset the flow pattern in the 55-gallon steel drum.

DISCUSSION OF RESULTS

Beran(1) has shown that the following equation describes the dispersion of a slug of material in passing through a granular bed, provided the flow is rapid enough to neglect diffusion.

$$C = \frac{W}{2A\sqrt{\pi KT}} \; e^{-\frac{(x-vT)^2}{4\,KT}} \qquad (1)$$

where: C = Concentration of tracer observed at x and T.

W = Mass of tracer introduced at x = 0 and T = 0.

A = Cross sectional area of bed.

T = Time of observation of C at x.

x = Distance along tank to point of observation of C

v = Mean velocity through the voids.

K = Dispersion parameter. This is a function of velocity and grain size and is equal to K'vd, where d is a measure of grain size, taken here as equal to the effective size, and K' is a dimensionless constant, dependent only on shape and packing.

For the equation to be useful as a rational basis for designing a chlorine contact tank, the constant K' must be evaluated. This can be done by plotting the flow-through data obtained from the experimental tanks on arithmetic probability paper and picking off the standard deviation corresponding to the first portion of the flow tracer. (See Figures 8 through 20). The standard deviation (σ_o) of the dimensionless plots in the Appendix is related to K' as follows:

By definition the standard deviation of equation (1) is:

$$\sigma_x^2 = (2KT)^{\frac{1}{2}} = (2K'vdT)^{\frac{1}{2}} \qquad (2)$$

where σ_x = The standard deviation with length units.

Rearranging:

$$K' = \frac{\sigma_x^2}{2\,vdT} \qquad (3)$$

The following relationships are noted:

$$\sigma_x = \sigma_t\,v$$

$$\sigma_t = \sigma_o T_o$$

$$T_o = \frac{AL}{Q}$$

$$v = \frac{Q}{Af}$$

where: σ_t = the standard deviation with units of time.

σ_o = the standard deviation of the dimensionless plot

A = cross sectional area of the tank

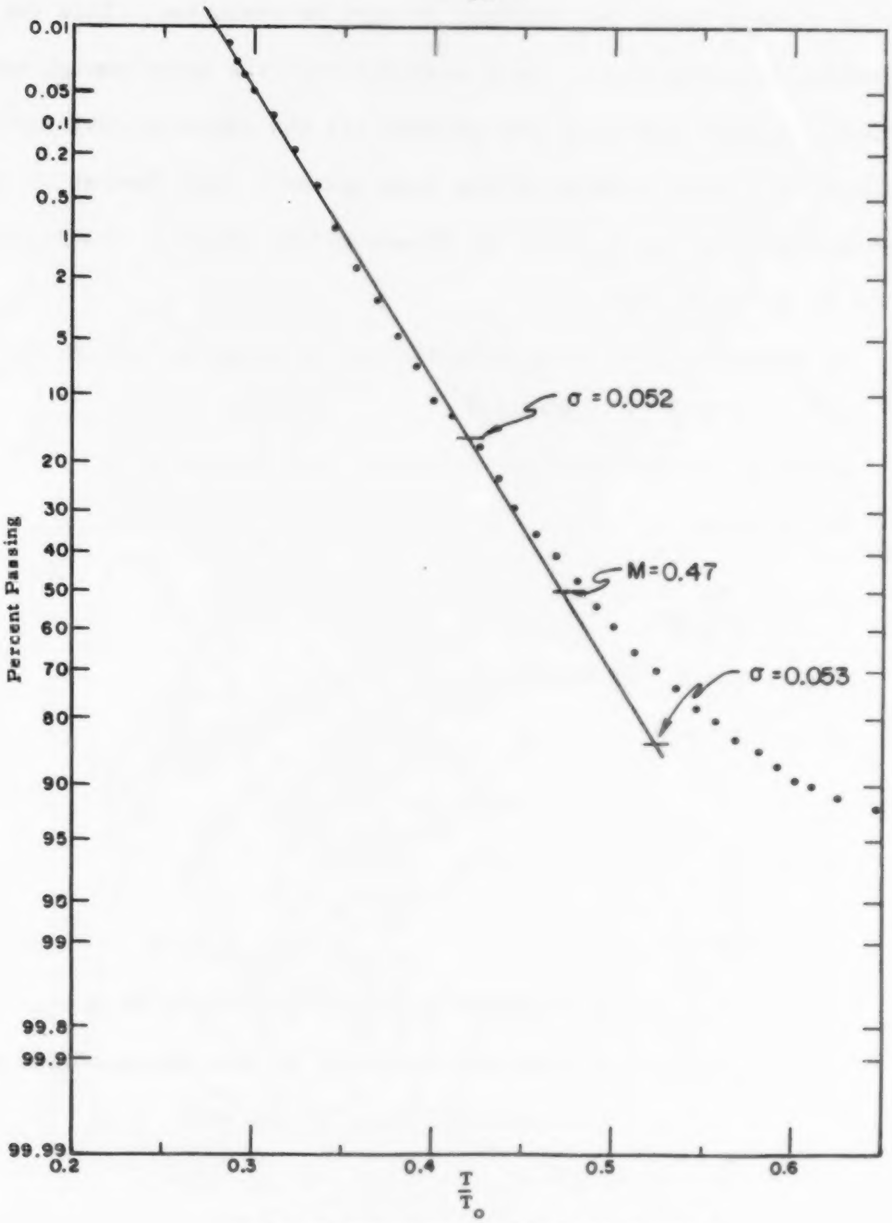
L = length of the tank

Q = discharge

f = void ratio of the gravel

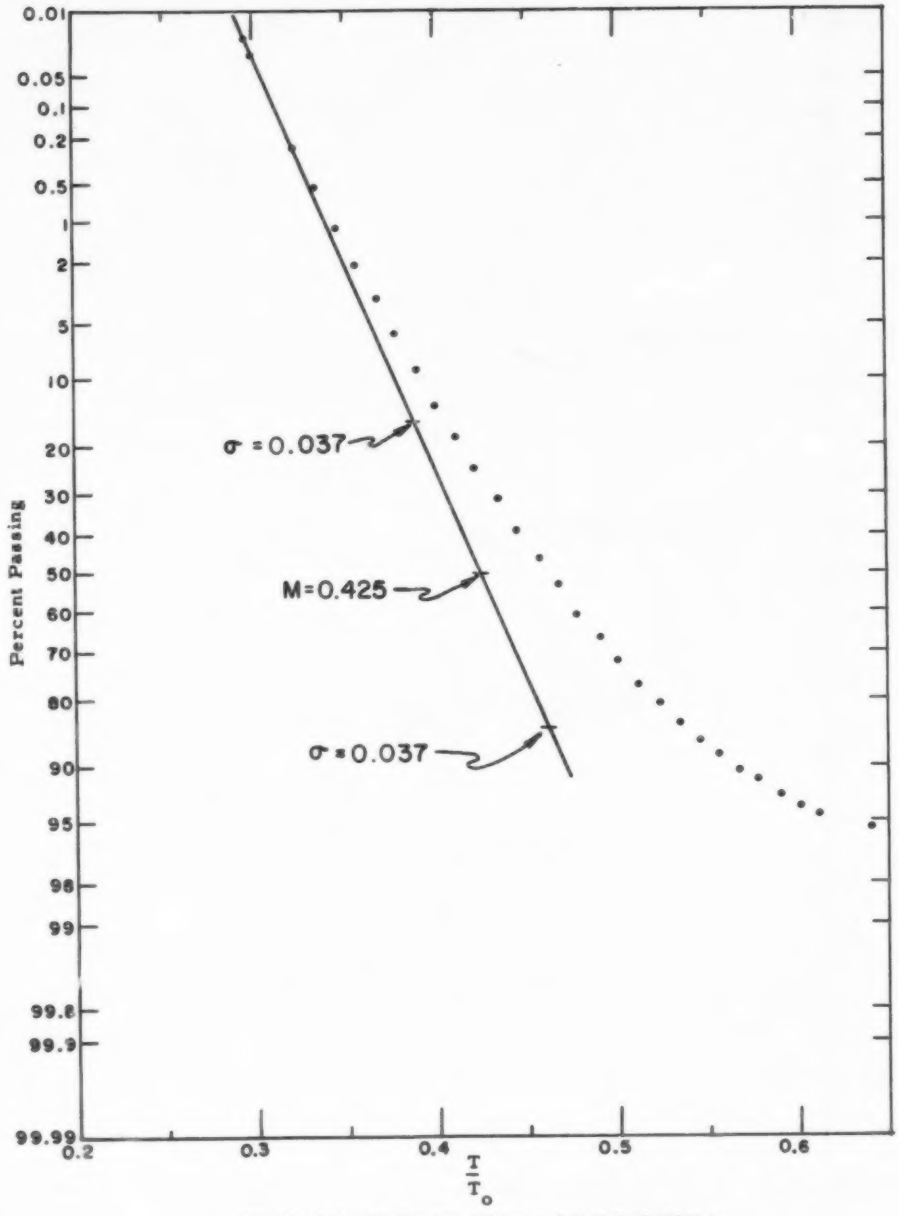
Substituting the above relationships:

$$K' = \frac{\sigma_o{}^2 T_o^2 v}{2\,Td} = \frac{\sigma_o{}^2}{2\,\frac{T}{T_o}d} \quad \frac{AL}{Q} \quad \frac{Q}{Af}$$



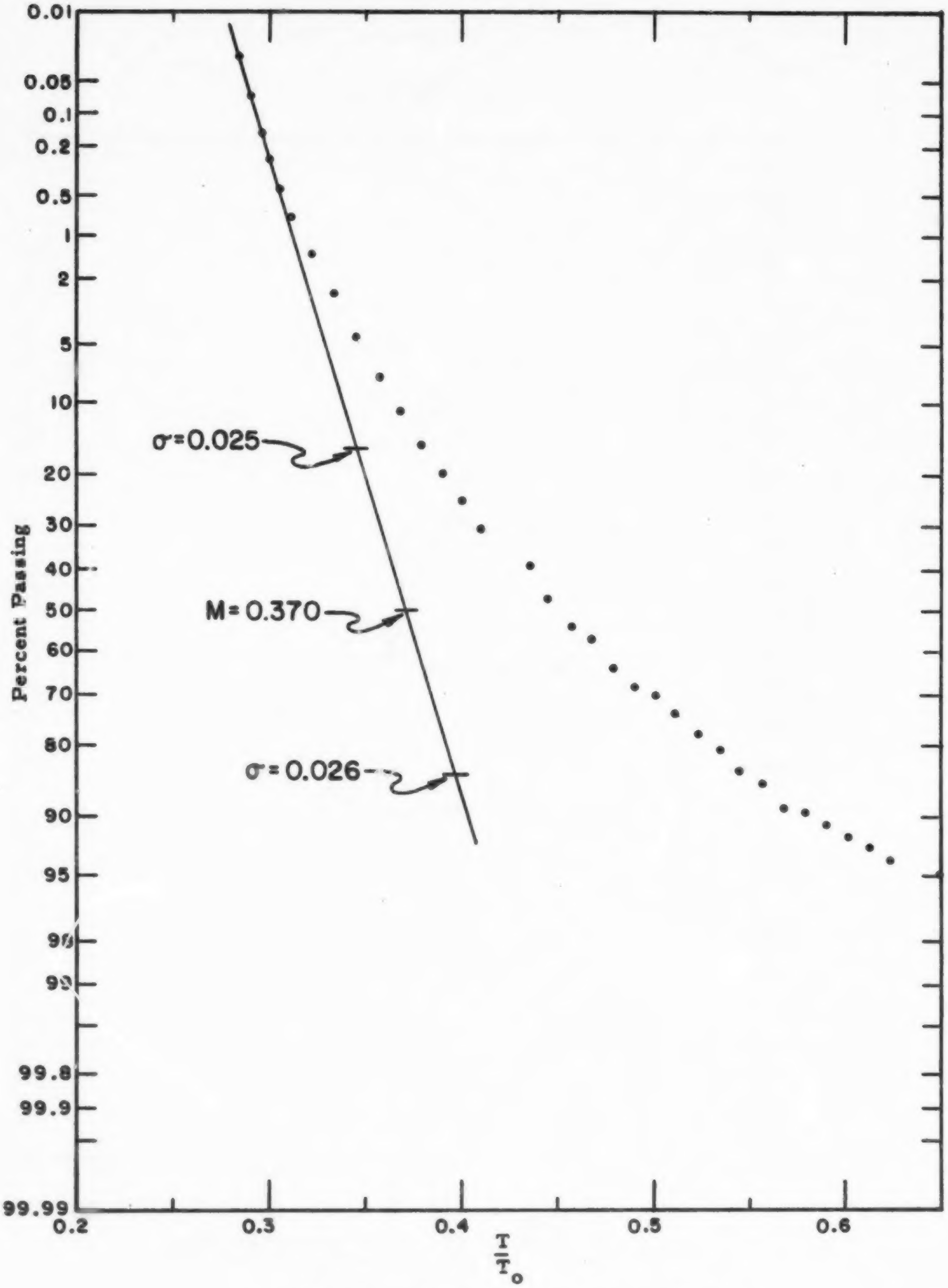
PROBABILITY PLOT FOR FLOW THROUGH A
15-FOOT TANK, Q = 2.65 GPM, V = 0.00206 FPS
APRIL 18, 1957

Figure 8



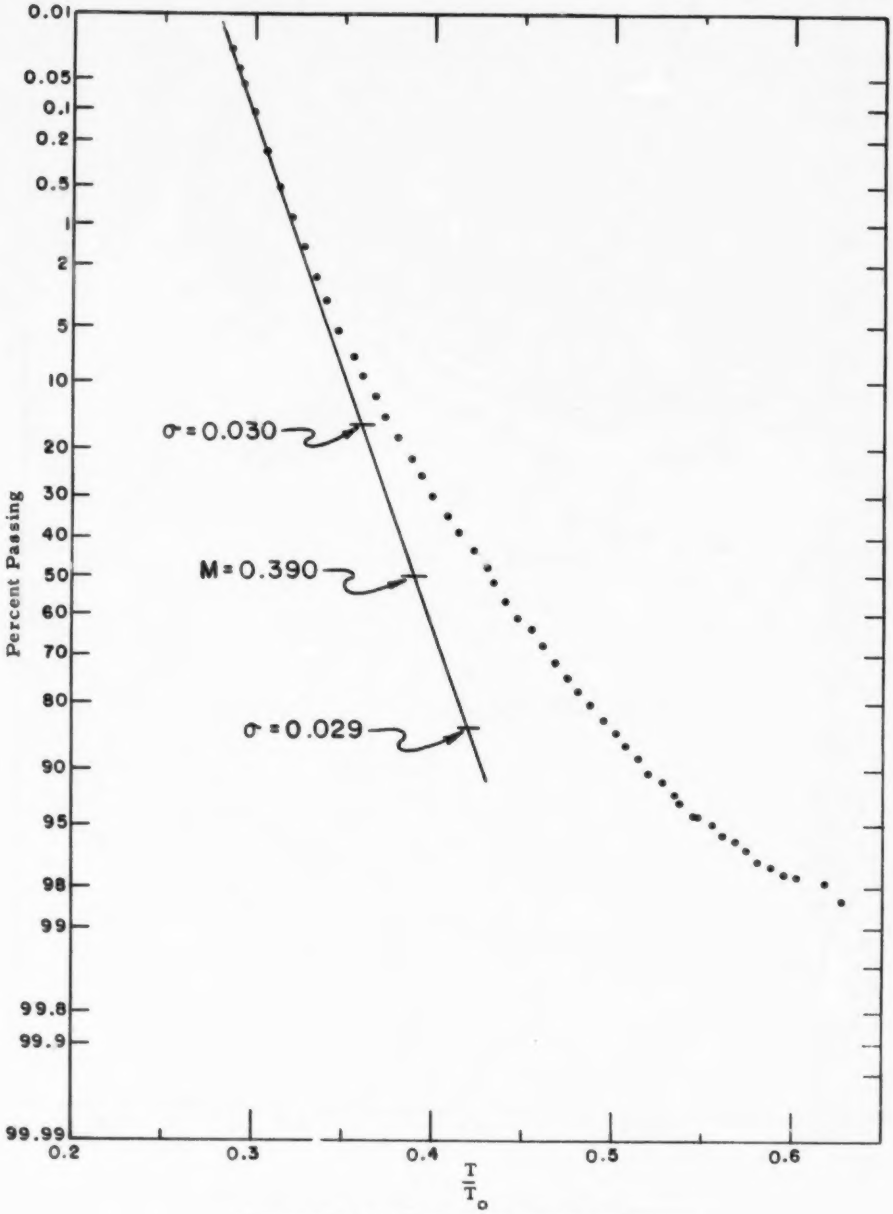
PROBABILITY PLOT FOR FLOW THROUGH A
15-FOOT TANK, Q = 2.65 GPM, V = 0.00206 FPS
APRIL 22, 1957

Figure 9



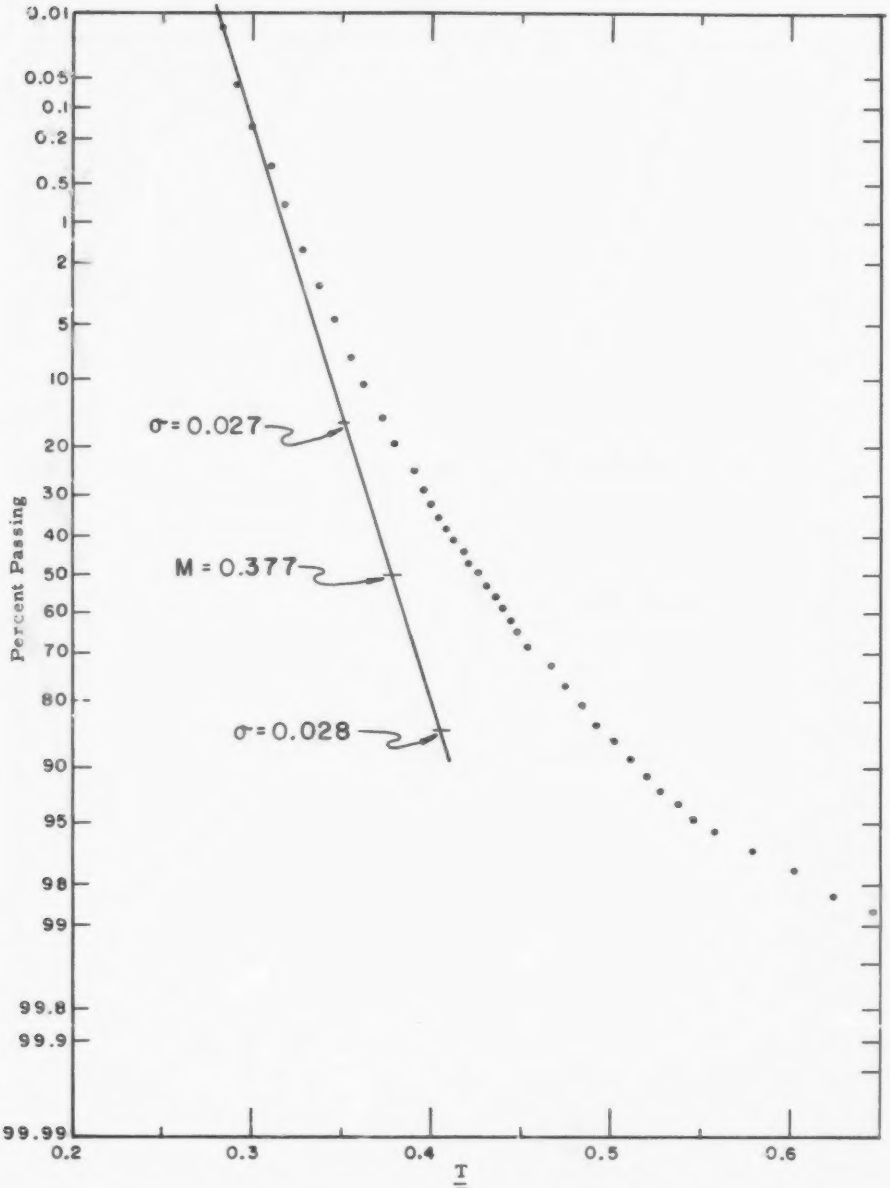
PROBABILITY PLOT FOR FLOW THROUGH A
15-FOOT TANK, Q = 2.65 GPM, V = 0.00206 FPS
APRIL 23, 1957

Figure 10



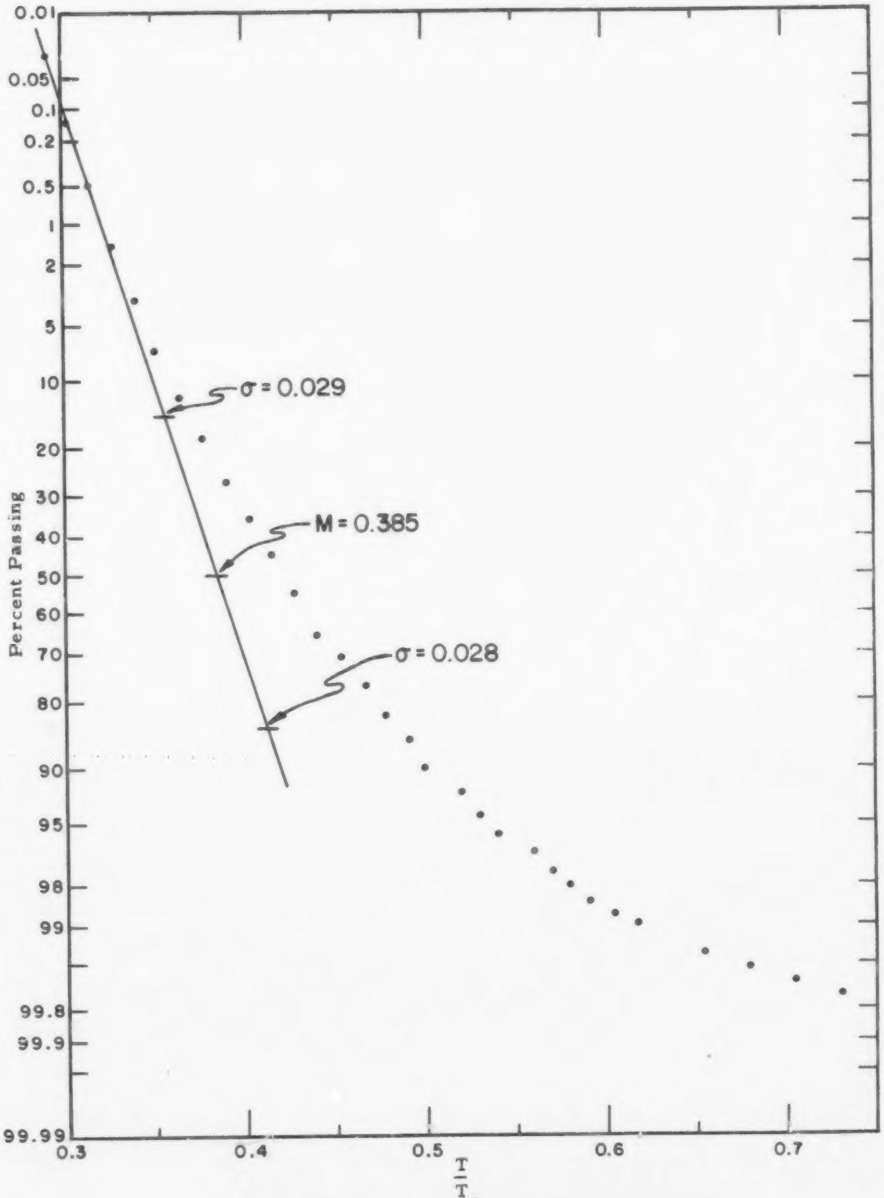
PROBABILITY PLOT FOR FLOW THROUGH A
15-FOOT TANK, Q = 10.6 GPM, V = 0.00825 FPS
APRIL 9, 1957

Figure 11



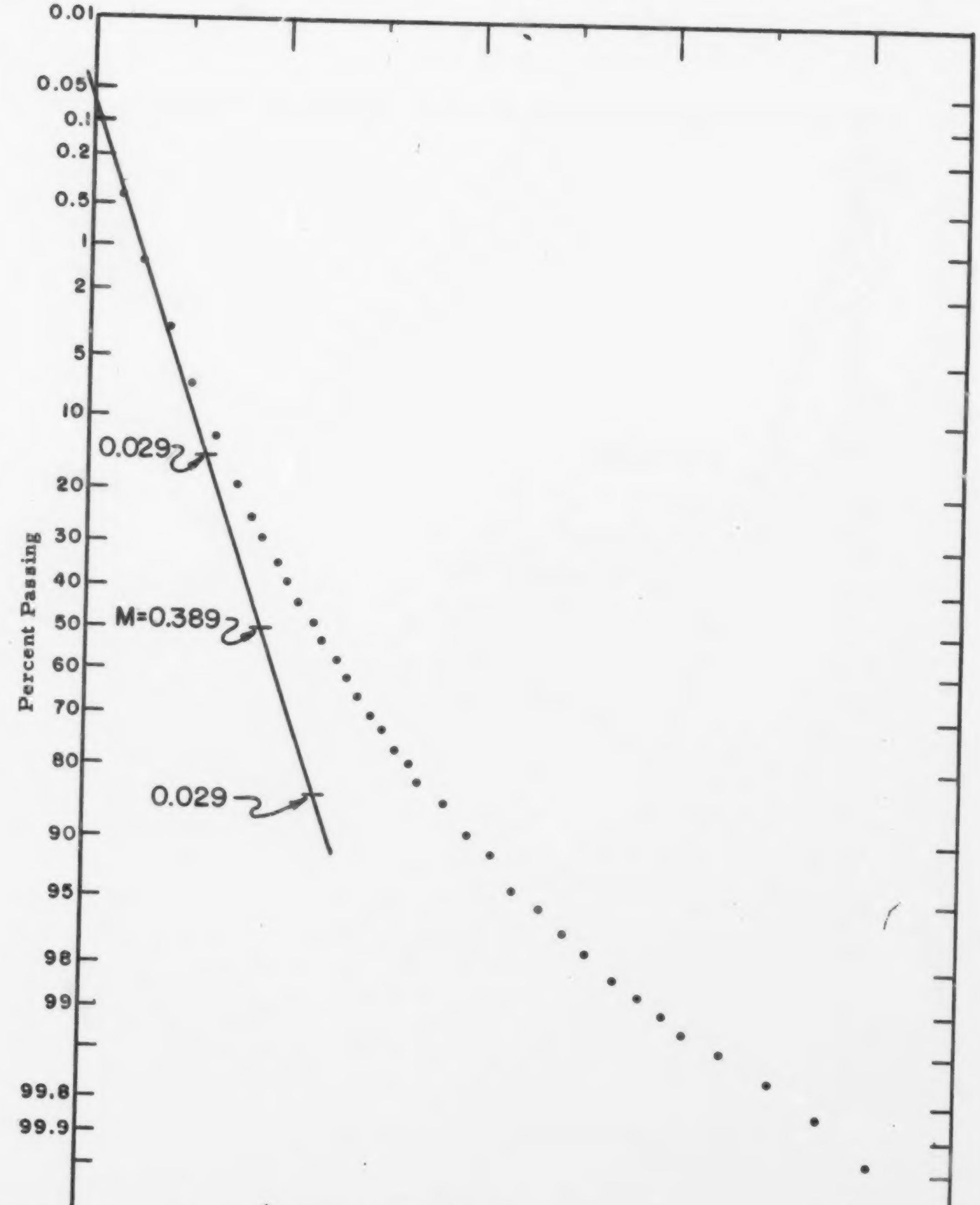
PROBABILITY PLOT FOR FLOW THROUGH A
15-FOOT TANK, Q = 10.6 GPM, V = 0.00825 FPS
APRIL 11, 1957

FIGURE 12



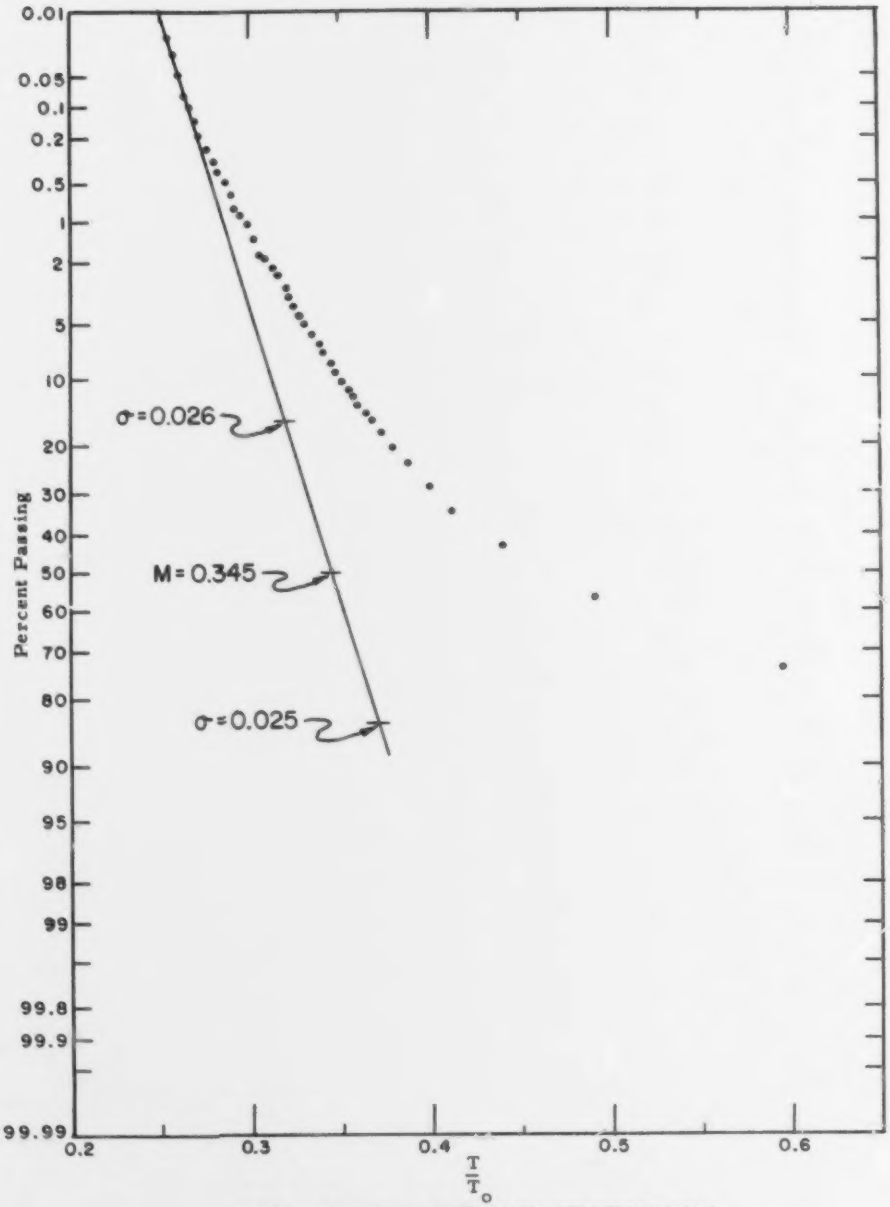
PROBABILITY PLOT FOR FLOW THROUGH A
15-FOOT TANK, Q = 30 GPM, V = 0.02 FPS
APRIL 25, 1957

Figure 13



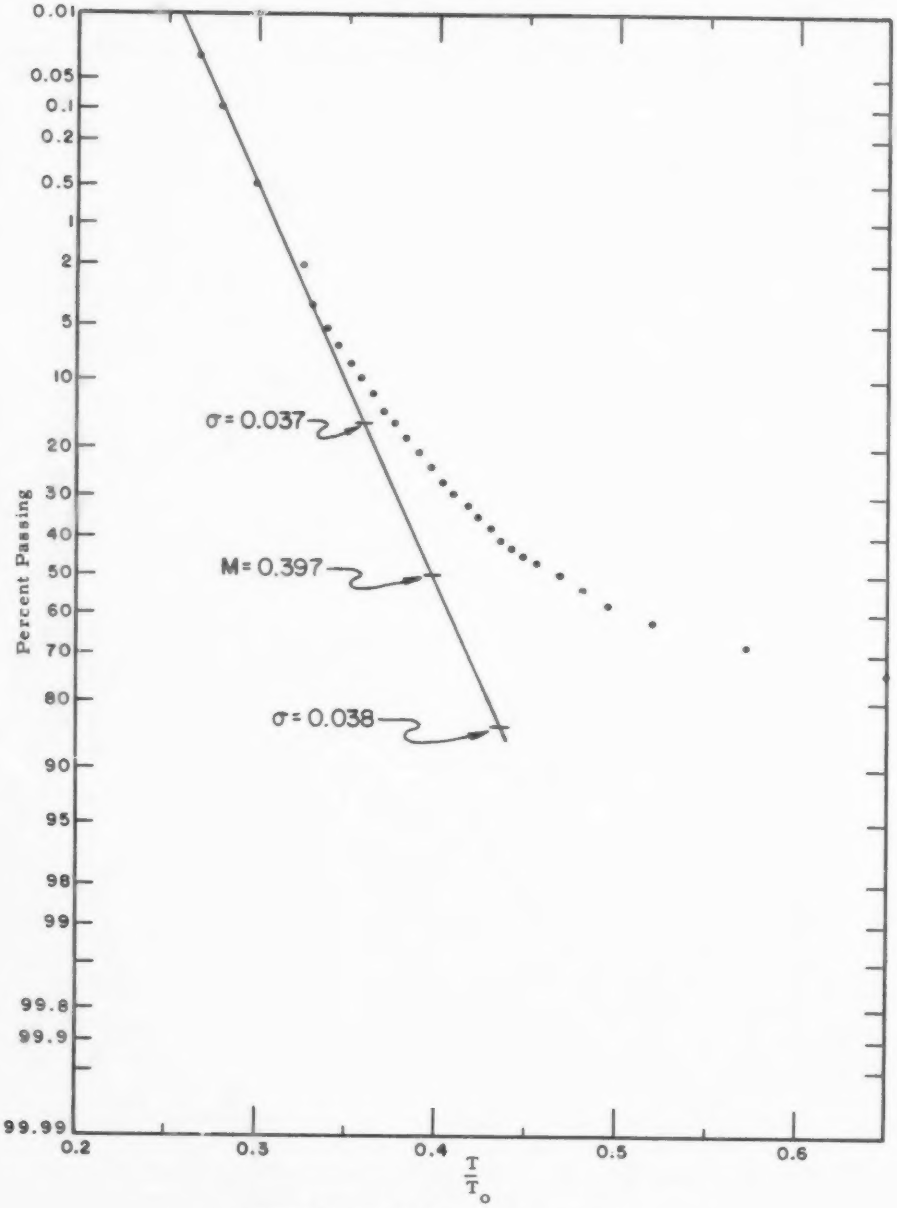
PROBABILITY PLOT FOR FLOW THROUGH A 15-FOOT TANK,
Q = 30 GPM, V = 0.0233 FPS
April 26, 1957

Figure 14



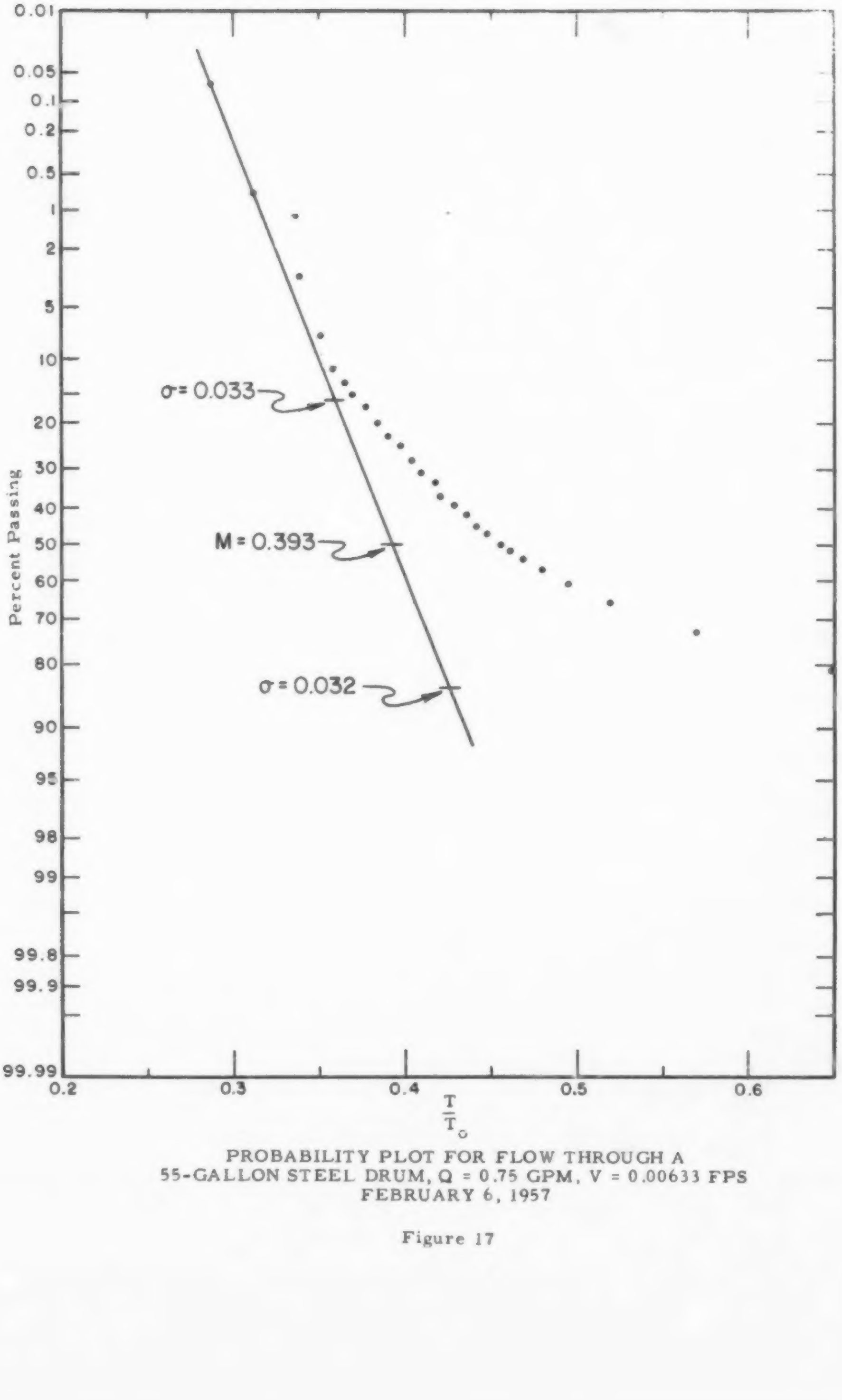
PROBABILITY PLOT FOR FLOW THROUGH A
55-GALLON STEEL DRUM, Q = 0.75 GPM, V = 0.00633 FPS
JANUARY 25, 1957

Figure 15



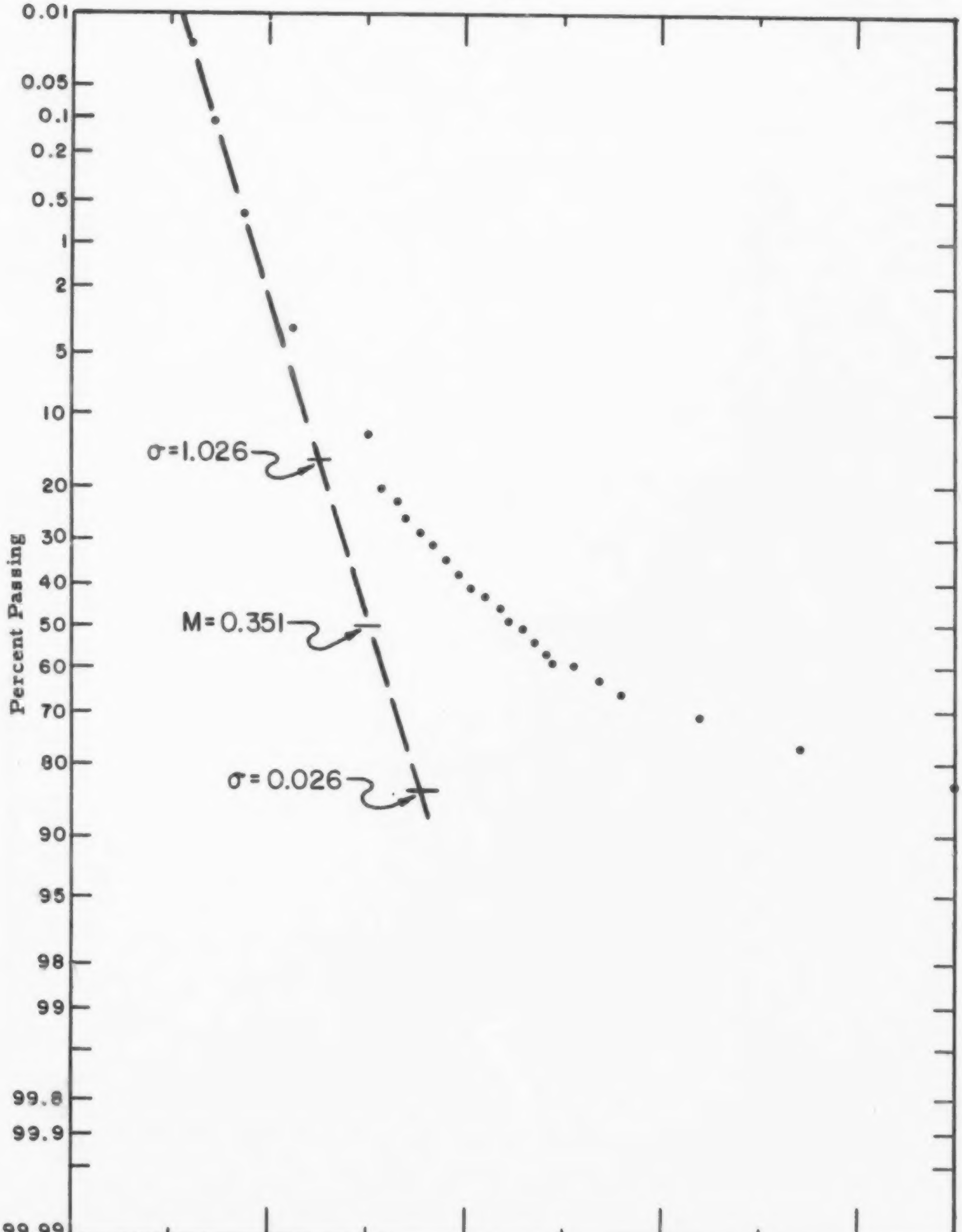
PROBABILITY PLOT FOR FLOW THROUGH A
55-GALLON STEEL DRUM, Q = 0.75 GPM, V = 0.00633 FPS
JANUARY 29, 1957

Figure 16



PROBABILITY PLOT FOR FLOW THROUGH A
55-GALLON STEEL DRUM, Q = 0.75 GPM, V = 0.00633 FPS
FEBRUARY 6, 1957

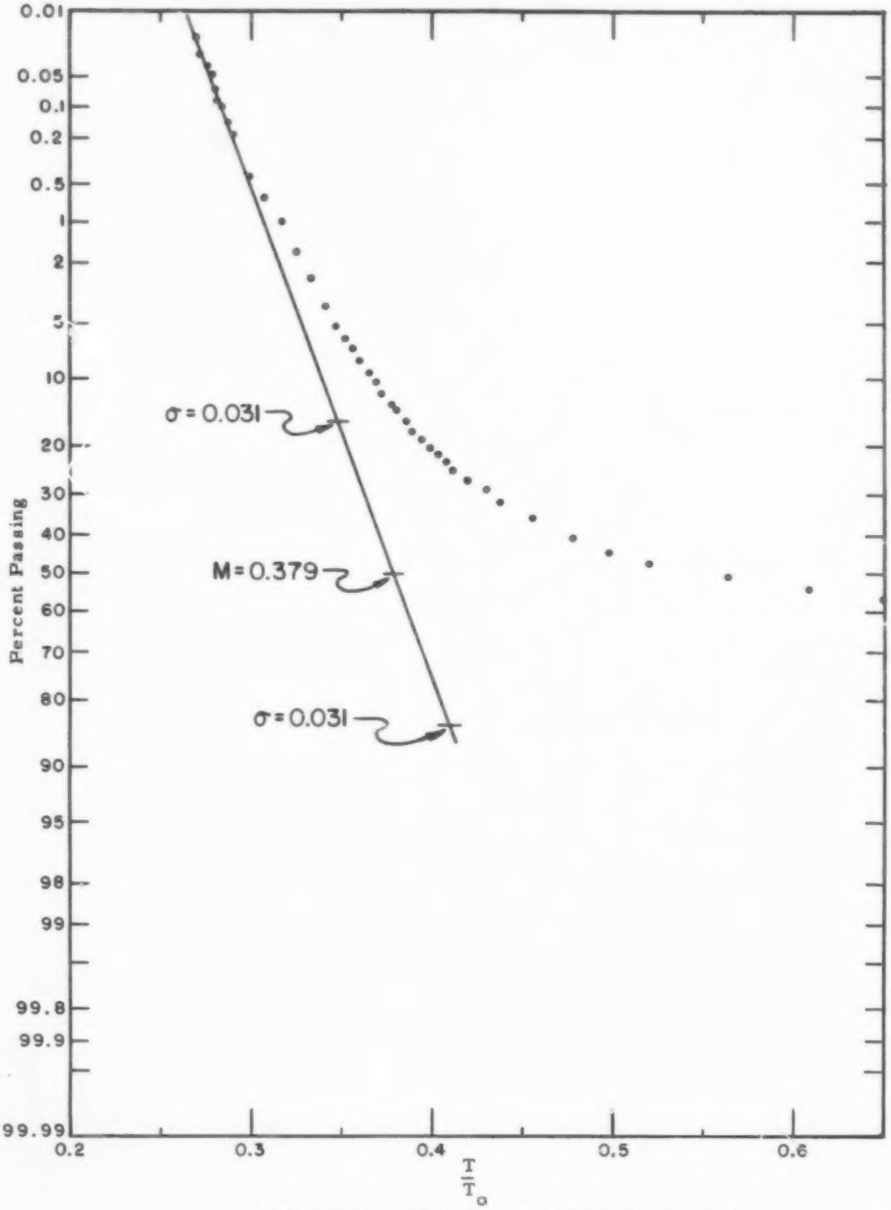
Figure 17



$\frac{T}{T_o}$

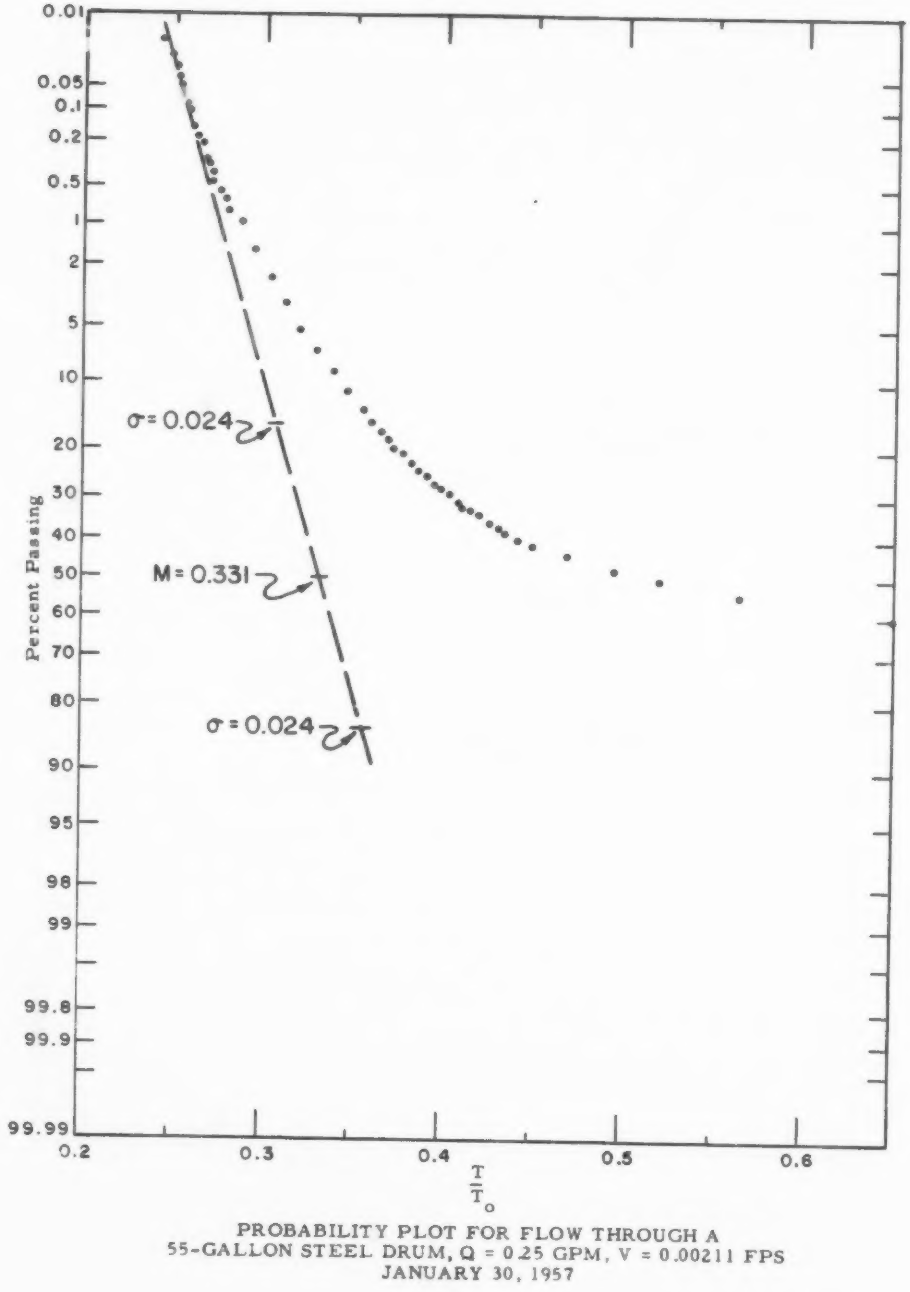
PROBABILITY PLOT FOR FLOW THROUGH A
55-GALLON STEEL DRUM, Q = 0.75 GPM, V = 0.00633 FPS
FEBRUARY 7, 1957

Figure 18



PROBABILITY PLOT FOR FLOW THROUGH A
55-GALLON STEEL DRUM, Q = 0.25 GPM, V = 0.00211 FPS
JANUARY 28, 1957

FIGURE 19



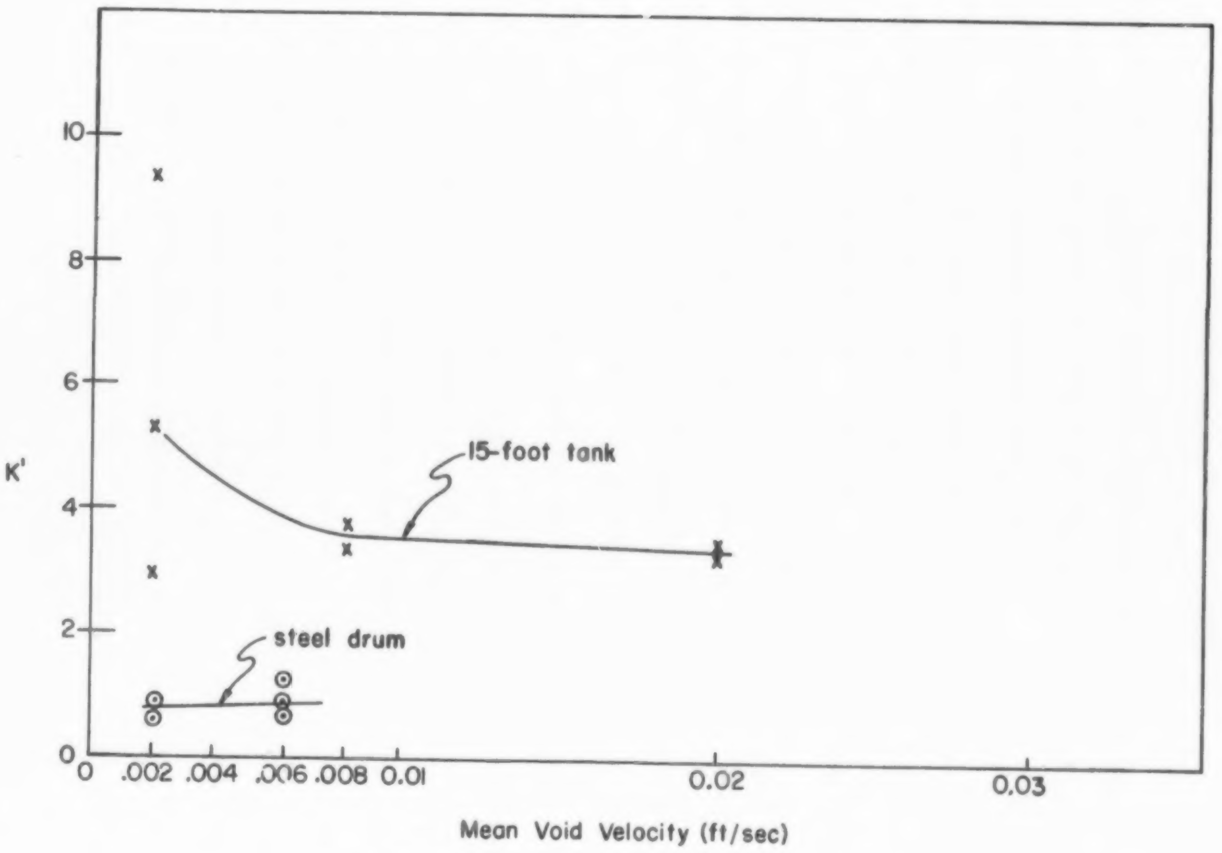
PROBABILITY PLOT FOR FLOW THROUGH A
55-GALLON STEEL DRUM, Q = 0.25 GPM, V = 0.00211 FPS
JANUARY 30, 1957

Figure 20

$$K' = \frac{\sigma_o^2}{\frac{\bar{T}}{T_o}} \left(\frac{L}{2\ fd}\right) \qquad (4)$$

For any particular tank, the quantity $\left(\frac{L}{2\ fd}\right)$ is constant. For each experimental run a straight line has been drawn on an arithmetic probability plot connecting the first several points, corresponding to the initial trace. These first points were used since the purpose of this analysis is to predict rationally the first trace time. The value of K' was calculated from the mean$\left(\frac{\bar{T}}{T_o}\right)$and standard deviation ($\sigma$) obtained from this straight line. The values of K' obtained from both the 15-foot tank and the 55-gallon steel drum are plotted on Figure 21, versus the mean void velocity. The information is also given in Table I. The plot shows that a K' value greater than 4 would be a safe value for design purposes, provided the mean void velocity is greater than 0.006 ft/sec. and the granular media used is similar to the pea gravel in these tests.

If equation (1) were followed perfectly, the data would plot as a straight line on arithmetic probability paper. The fact that it does not indicates the extent of inlet and outlet interference in the tanks; even so, the results show that Beran's equation characterizes the flow pattern satisfactorily for practical purposes. Since Beran's equation was found to characterize the flow, it is possible to predict the behavior and flow pattern for other installations.



VALUES OF K' CORRESPONDING TO INITIAL TRACE

Figure 21

TABLE I

VALUES OF K' CORRESPONDING TO INITIAL DYE TRACE

Date of Run	Mean Void Velocity	σ_o	$\frac{T}{T_o}$	$\frac{L}{2\,fd}$	K'
15-foot tank:					
4/18/57	0.00206 ft/sec.	0.052	0.47	1625	9.34
4/22	0.00206	0.037	0.425	1625	5.24
4/23	0.00206	0.026	0.470	1625	2.97
4/9	0.00825	0.030	0.390	1625	3.75
4/11	0.00825	0.028	0.377	1625	3.38
4/25	0.0233	0.028	0.385	1625	3.31
4/26	0.0233	0.029	0.389	1625	3.51
55-gallon steel drum					
1/25/57	0.00633 ft/sec.	0.026	0.345	341	0.668
1/29	0.00633	0.038	0.397	341	1.24
2/6	0.00633	0.032	0.393	341	0.888
2/7	0.00633	0.026	0.351	341	0.657
1/28	0.00211	0.031	0.379	341	0.865
1/30	0.00211	0.024	0.331	341	0.594

CONCLUSIONS

1. Low velocity flow through unbaffled cylindrical tanks is not sufficiently stable to recommend their use as chlorine contact tanks.
2. Flow through pea gravel is a practical method of providing time for chlorine contact without appreciable short-circuiting.
3. The equation of Beran has been shown to describe reasonably well the longitudinal dispersion of flow through pea gravel, and the equation is suitable as a basis for design.
4. The dispersion parameter K' has been evaluated for the "first trace" flow through pea gravel. For design purposes a value greater than 4 appears safe, provided the mean void velocity is greater than 0.006 ft/sec.

DESIGN OF A CHLORINE CONTACT TANK

Equation (1), describing the flow dispersion through granular media, is taken as the basis of design. The time (t_c) when the "first trace" arrives at the outlet is defined, arbitrarily but conservatively, as that time when 3×10^{-7} of the total tracer has passed the tank outlet. If equation (1) were a normal probability curve in time this would occur five standard deviations (5σ) ahead of the mean. Even though equation (1) is not quite normal in time, it is near enough so that the following relationship may be taken as correct for design purposes.

$$L - vt_c = 5\sigma$$

From equation (1) and the definition of K, the standard deviation is:

$$\sigma = (2K'vt_cd)^{\frac{1}{2}}$$

then:

$$L - vt_c = 5(2K'vt_cd)^{\frac{1}{2}}$$

Rearranging and taking $\frac{L}{v}$ = To, the theoretical detention time:

$$\frac{t_c}{T_o} = 1 + \frac{25\,K'd}{L} \pm \sqrt{(2 + (\frac{25\,K'd}{L})\,(\frac{25\,K'd}{L})}$$

This equation, the porosity of a gravel (f), and the following relationship are all that is required for design:

$$v = \frac{t_c}{T_o}\,\frac{L}{t_c}$$

DESIGN EXAMPLE

Problem: Calculate the inside dimensions of a gravel filled chlorine contact tank for 5-minute and 15-minute detention.

Given: Average Flow Rate = 100,000 gpd

Maximum Flow Rate = 300,000 gpd

$K' = 5$

Effective size of pea gravel (d) = 0.13 inches

Porosity (f) = 0.35

Assume height of tank L = 15 ft.

Solution: To solve for the dimensions of the tank the height L must be assumed and A, cross section area, calculated. If these are not satisfactory another L may be assumed and the calculations repeated.

$$\frac{t_c}{T_o} = 1 + \frac{25\,K'd}{L} \pm \sqrt{(2 + \frac{25\,K'd}{L})\,(\frac{25\,K'd}{L})}$$

$$= 1 + \frac{25(5)(\frac{0.13}{12})}{15} \pm \sqrt{(2 + \frac{25(5)(\frac{0.13}{12})}{15})\,(\frac{25(5)(\frac{0.13}{12})}{15})}$$

$$= 1 + .0903 \pm \sqrt{(2.0903)(0.0903)} = 1.0903 \pm 0.435$$

Use minus sign since plus sign corresponds to 5σ past mean.

$\frac{t_c}{T_o}$ = 0.655 (First trace efficiency)

For tank with 5 minute detention t_c = 300 sec.

$$v = \left(\frac{t_c}{T_o}\right)\left(\frac{L}{t_c}\right)$$

$$v_5 = 0.655 \quad \frac{15 \text{ ft.}}{300 \text{ sec.}} = 0.05 \text{ ft/sec.}$$

$$v_{15} = 0.655 \quad \frac{15 \text{ ft.}}{900 \text{ sec.}} = 0.0167 \text{ ft/sec.}$$

5^m Detention

Area of tank $(A)_5 = \frac{Q}{vf} = \frac{0.3 \times 1.54}{0.05 \times 0.35} = 26.4$ sq.ft.

Concrete tank dimensions $\sqrt{26.4} = 5.14$ ft.

Inside dimensions 5' - 2" x 5' - 2" x 17' - 0"

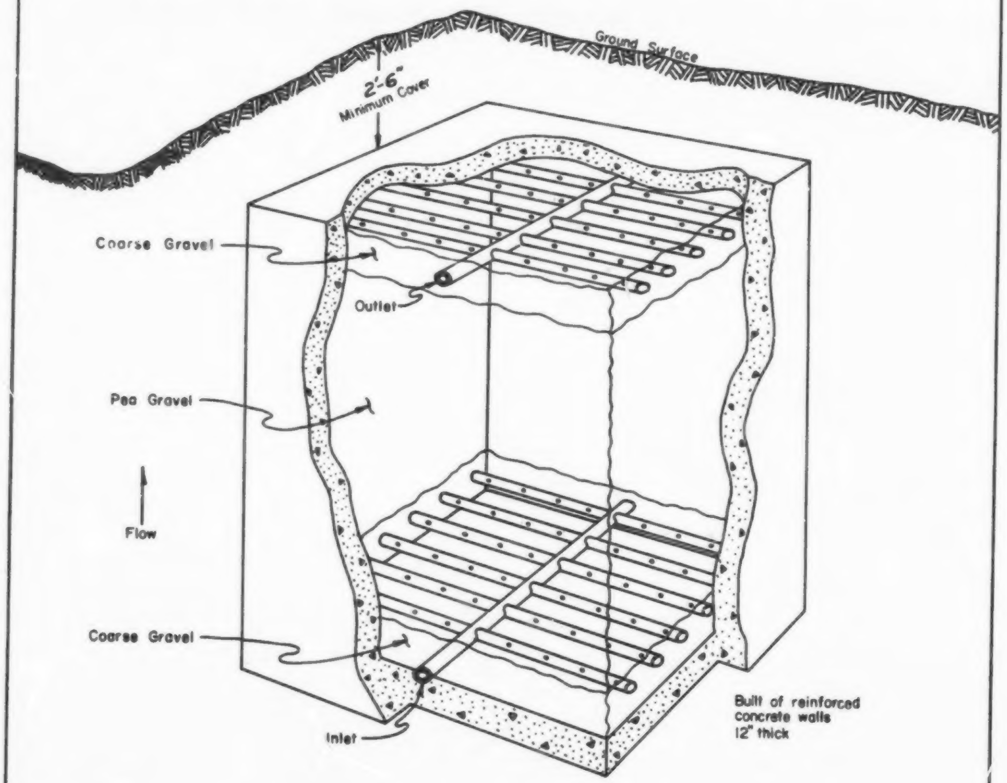
(Allowance of 2' was made in the tank height for flow distribution and collection systems)

Steel tank diameter $D = \sqrt{\frac{4}{\pi} A} = \sqrt{\frac{4}{\pi}(26.4)} = 5.88'$

If the direction of flow in the chlorine contact tank is chosen upward, the distribution system will be located on the tank bottom. One satisfactory distribution system may be constructed by using perforated pipes, as in a sand filter underdrain, with the perforations in a horizontal plane. The holes should be small enough to insure good distribution by providing a sufficiently large, controlling head loss. The pipes can rest on the tank bottom and be connected through suitable laterals and headers to the inlet pipe, probably most conveniently located on the side of the tank. Coarse gravel should surround and cover the distribution system to about a foot.

Other standard type filter underdrain systems should serve equally well.

The collecting system may be constructed in a manner similar to the distribution system. While there have been no experimental tests on the distribution system recommended above, it is not believed they are needed. Access ports in the cover should be provided. Figure 22 shows a sketch of a typical chlorine contact tank constructed of reinforced concrete.


Ground Surface
2'-6"
Minimum Cover
Coarse Gravel
Outlet
Pea Gravel
Flow
Coarse Gravel
Inlet
Built of reinforced concrete walls 12" thick

Typical Chlorine Contact Tank
Figure 22

REFERENCE

1. Beran, Mark Jay. Thesis to the Division of Applied Science for the Degree of Doctor of Philosophy in the Subject of Engineering, Harvard University, Cambridge, Mass., May, 1955.

APPENDIX E

Estimated Costs for Re-treating Water To Protect Against Spores, Vegetative Bacteria or Toxin

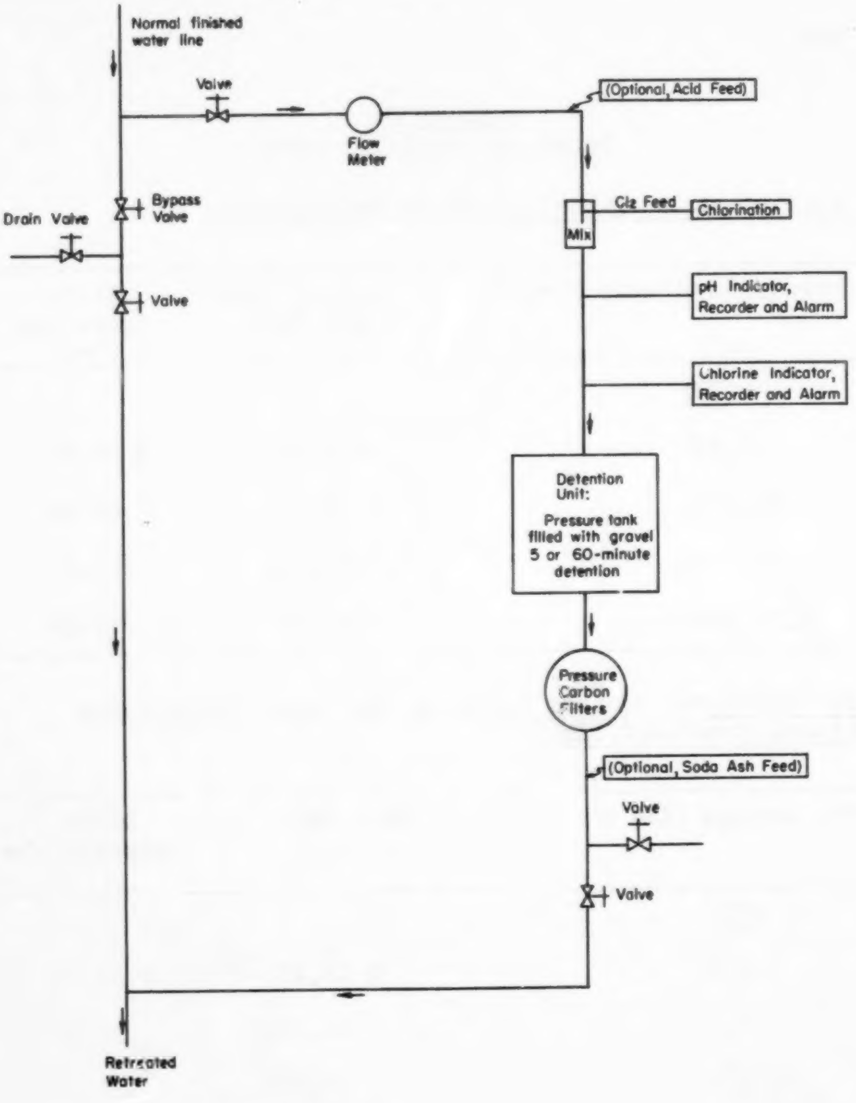
INTRODUCTION

Cost estimates were made for re-treating finished water using a long length of pipe or a gravel-filled tank as the basic detention unit to assure proper chlorination. It was determined that a concrete tank would be less expensive and yet as efficient. Buildings, pipe, valves, fittings, feeders, filters, indicators, etc., will cost about the same for either type of detention unit so these costs have been listed in this appendix along with the costs for a tank. Tank length to width ratios were selected so as to be similar to those in the experiments performed at this Center, and 15-feet was considered a minimum depth.

Only prices of water treatment equipment commercially available have been used, and these items have been amortized over a 10-year period at 2.5 percent interest. Totals include cost of installation and maximum daily chemical use as well as all piping and equipment.

Costs have been estimated for two types of plants:

1. High chlorine residual plant with a 60-minute detention to protect against spores for average continuous flows of 25,000, 100,000, 500,000 or 1,000,000 gpd, with the maximum flow being considered to be 3 times the average.
2. Low chlorine residual plant with a 5-minute detention to protect against vegetative bacteria or toxin for continuous flows of 25,000, 100,000, 500,000 or 1,000,000 gpd. A basic flow diagram is shown on the next page.


Normal finished water line
Valve
Flow Meter
(Optional, Acid Feed)
Bypass Valve
Drain Valve
Valve
Cl_2 Feed
Chlorination
Mix
pH Indicator, Recorder and Alarm
Chlorine Indicator, Recorder and Alarm
Detention Unit:
Pressure tank filled with gravel 5 or 60-minute detention
Pressure Carbon Filters
(Optional, Soda Ash Feed)
Valve
Valve
Retreated Water

BASIC FLOW DIAGRAM OF RE-TREATMENT PLANT

In addition, equipment costs and daily operating costs have been computed for modifying conventional treatment plants in the 05 to 10 MGD range.

SUMMARY OF
PLANT AND OPERATING COSTS

Cost for Protection Against Spores by Re-treatment:

For Average Continuous Flow of:	Cost of Unit with Tank	Daily Operating Cost
GPD		
25,000	$ 37,000	$ 20.78
100,000	59,000	42.44
500,000	157,000	140.90
1,000,000	274,000	269.40

Cost for Protection Against Spores in Raw Water by Modifying Conventional Treatment Plant:

For Average Flow of:	Total Cost	Daily Operating Cost
MGD		
0.5	$ 14,150	$ 22.20
1	16,060	37.10
5	20,900	120.00
10	28,600	216.00

SUMMARY OF
PLANT AND OPERATING COSTS
(Cont'd.)

Cost for Protection Against Vegetative Bacteria or Toxin by Re-treatment:

For Average Continuous Flow of:		Total Cost of Unit with Tank	Daily Operating Cost
	GPD		
	25,000	$ 17,600	$ 9.37
(with carbon filters)	100,000	30,000	16.61
(without " ")	100,000	14,000	8.81
	500,000	80,000	52.45
	1,000,000	135,200	89.57

EXAMPLE OF THE METHOD FOR DETERMINING TANK SIZE AND COST

Basis of Design (see Appendix D)

Detention time: --- 1 hour

Average flow: ----- 0.025 mgd

Maximum flow: ----- 0.075 mgd = 0.116 cfs

Use: 15' deep tank

K' = (Dispersion parameter) = over 4, so use 5

d = E.S. = Effective size of pea gravel = 0.13" = $\frac{0.13}{12}$ feet

U.C. = uniformity coefficient of gravel = 1.75

f = porosity = 0.35

Solution. To determine dimensions of the tank, the height, L, must be assumed and the cross-sectional area, A, calculated. If these are not satisfactory, another L may be assumed and the calculations repeated.

1. Determine the first trace efficiency, $\frac{t_c}{T_o}$

$$\frac{t_c}{T_o} = \frac{1 + 25\,K'd}{L} \pm \sqrt{\left(2 + \frac{25K'd}{L}\right)\left(\frac{25K'd}{L}\right)}$$

$$= 1 + (25)(5)\left(\frac{0.13}{12}\right) \pm \sqrt{(2.0902)(0.0903)} = 1.0903 \pm 0.435$$

$$= 1.0903 - 0.435 \approx 0.655 \text{ for first trace}$$

$$\text{Velocity} = \frac{t_c}{T_o}\;\frac{L}{t_c} = 0.655 \times \frac{15}{3600} = 0.00274$$

$$A = \frac{\text{discharge in cfs}}{\text{velocity x porosity}} = \frac{0.116}{0.00274} \times 0.35 = 120 \text{ sq.ft.}$$

Select cross section of 11' x 11'

Volume of concrete necessary:

Assume 1-foot thick walls and an extra foot on each end of tank for distribution and collection system so inside dimensions are 11' x 11' x 17'.

2 sidewalls then are: 17 x 11 x 2 = 374

2 end walls: 17 x 13 x 2 = 442

Top & bottom: 13 x 13 x 2 = 338

Total = 1154 cu.ft.

= 42.7 cu.yds.

Use: 43

Cost Estimate:

Concrete at $80/cu.yd.	= 43 x 80 =	$ 3,450
Excavation at $6/cu.yd.	= $\frac{11 \times 11 \times 20}{27} \times 6$ =	540
Gravel at $4/cu.yd.	= $\frac{11 \times 11 \times 17}{27} \times 4$ =	300
Under drain system		800
Piping		800
		5,890
	10% Installation, etc.	589
		$ 6,479
	Use:	6,500

All other tank sizes and costs were determined in a similar manner.

SUMMARY OF TOTAL COSTS OF CONSTRUCTION FOR CONCRETE, GRAVEL-FILLED HOLDING TANK

Flow, GPD Avg.	 Max.	5-Minute Period	60-Minute Period
25,000	75,000	1,900	6,500
100,000	300,000	3,200	13,500
500,000	1,500,000	8,500	58,000
1,000,000	3,000,000	14,000	100,000

COST ESTIMATE FOR A
25,000 gpd, CONTINUOUS-FLOW, RE-TREATMENT SYSTEM WITH LOW CHLORINE RESIDUAL FOR PROTECTION AGAINST VEGETATIVE BACTERIA AND TOXIN

Item	Description	Cost
1	Building to house system built of cement block, flat roof, no architectural treatment, built by private contractor.	$ 3,500
2	4" Bypass Valve 125# Iron Body Wedge, Gate Valves, $20 each.	40
3	2" Bypass Drain Valve 125# Iron Body, Wedge Gate Valve	15
4	4" Bypass pipe and fittings	161
5	3" Treatment Entrance Valve 125# Iron Body Wedge Gate Valve	20
6	Flow meter and Transmitter	300
7	Residual Chlorine Recorder	3,000
8	pH indicating and Recording Instrument Chlorine Feed Pump 2 Chlorine Solution Tanks $300 each (approx. 135 gal.ea.)	1,200 653 600
9	Temperature Indicator and Recorder.	280
10	3" Cast Iron Flanged pipe and fittings - Treatment line within building.	170
11	Chlorine Contact tank, concrete, 4' x 4' x 17', 5-minute detention period--complete with gravel, excavation, laying and backfilling.	1,900
12	1 Pressure Filter with appurtenant equipment	1,900
13	3" Bypass Valves for cleaning, flushing, adjusting system	45
14	Miscellaneous pipe and fittings	150
		$ 13,934
	10% for furnishing and maintenance equipment	1,393
		15,327
	15% Installation Estimate	2,300
	Approx.	$ 17,627

OPERATING COSTS

I. Chemicals

A. Chlorine when dose is 5 mg/l

Quantity = concentration x flow per day x conversion to lbs. =

$$5 \times 0.025 \times 8.33 = 1.04 \text{ lbs/day (average)}$$

Price of hypochlorite, HTH, with 70 percent available chlorine:

$0.28/lb.

Cost per day: $\frac{1.04 \times 0.28}{0.70} = \$0.43$

When dose is 8 mg/l

Cost per day: $\underline{\$0.43} \times 8/5 = \$0.69$

B. Carbon

Quantity necessary when carbon filter capacity for chlorine is 20 lbs/cu.ft. and filter dimensions are 2.5' in depth and 5' in diameter:

$$Q = \frac{\pi(5)^2}{4} \times 2.5 = 49.1 \text{ cu.ft./filter}$$

which has chlorine capacity of: 20 x 49.1 = 982 lbs.

since carbon cost = $7/cu.ft.

Daily Cost: Cost of a filter unit x fraction of filter used

$$\text{per day} = 7 \times 49 \times \frac{1.04}{982} = \$0.364/\text{day}$$

When a chlorine dose of 8 mg/l is used daily cost of carbon =

8/5 x $0.364 = $0.58

II. Utilities	$0.20/day
III. Labor	3.00/day

IV. Amortization

With an interest rate of 2.5 percent per year, the average annual cost of interest over a period of 10 years is approximately 1.25 percent, hence daily this cost is

$$\frac{1.0125 \times 17{,}627}{365 \times 10} = \$4.90$$

Total daily cost = \$9.37.

COST ESTIMATE FOR A 100,000 gpd, CONTINUOUS-FLOW, RE-TREATMENT SYSTEM WITH LOW CHLORINE RESIDUAL FOR PROTECTION AGAINST VEGETATIVE BACTERIA AND TOXIN

Item	Description	Cost
1	2, 8", 125 pound, iron body wedge gate valves for by-pass, $175.00 each.	$ 350
2	1, 2", 125 pound, iron body wedge gate valve for by-pass safety drain.	38
3	1, 6", 125 pound, iron body wedge gate valve for entrance valve to treatment system.	102
4	Mechanical Meter, 3" size, flow range, 30 to 315 gpm with 2% accuracy	702
5	Contact timer to operate solenoid in fresh water suction of pump.	103
6	Solenoid for fresh water supply to pump suction	40
7	Chlorine feed pump	300
8	2, Hypochlorite solution feed tanks with steel cover, gage glass dissolving device and 1/3 HP 220 volt, 60-cycle agitator, totally enclosed motor.	1,100
9	1, pH indicator, recorder with alarm contacts.	1,200
10	1, Chlorine indicator, recorder with alarm contacts	3,100
11	Chlorine contact tank for detention period of 5-minutes, concrete, 15' x 7' x 7', complete with gravel, excavation, laying, and backfilling.	3,200
12	2, Activated carbon filters - pressure type (including carbon) (84" diameter)	6,400
13	2, 4", 125 pound, iron body wedge gate valve for by-pass to waste to be used in flushing system, initiating operation, etc.	125
	Total	$ 16,760

Cost List (Cont'd.)

Item	Description	Cost
	Total, brought forward	$ 16,760
14	Building to house system. Needed if option of carbon filters is chosen. Otherwise, probably not necessary	7,000
15	Miscellaneous piping	500
	Total	$ 24,260
	Estimate an additional 10% for misc. items such as small piping, desk, chemical testing kits, etc.	2,426
	Estimate installation at an additional 15%	3,900
	Total	$ 30,586
	Use:	$ 30,000

Option without carbon filters and without building. Assume that space can be found in existing building for equipment.

Equipment Cost	10,860
Additional 10%	1,086
	$ 11,946
Installation, approx. 15%	1,700
Grand Total	$ 13,646
Use:	14,000

OPERATING COSTS

Continuous Flow System
Low Chlorine Residual with Carbon Filters

I. Chemicals

A. Chlorine when dose is 5 mg/l

Quantity = conctn x gpd x 8.33 = 5 x 0.1 x 8.33

= 4.17 lb/day

Price of hypochlorite (70% in HTH) = $\underline{\$0.2865/\text{lb}}$

Cost per day = $\frac{4.17}{0.7}$ = \$0.28 = $\underline{\$1.71}$

When dose is 8 mg/l, cost per day = $\underline{\$2.74}$

B. Carbon

Quantity when 2 filters are each 7' in diameter and 2.5' in depth = $\left(\frac{\pi(7)^2}{4} \times 2.5\right) 2$ = 192 cu.ft.

c.f. capacity for Cl_2 is 20 lb/cu.ft.

Cost per cu.ft. = \$7

Cost per day = $7 \times 192 \times \frac{4.17}{20 \times 192}$ = $\underline{\$1.46}$

When chlorine dose is 8 mg/l, cost = 8/5 x 1.46 = $\underline{\$2.34}$/day

II. Utilities \$0.20 per day

III. Labor 3.00 per day

IV. Amortization 8.33 per day

$$\frac{30{,}000 \times 1.0125}{10 \times 365} = \$8.33$$

Total at 5 mg/l \$ 14.70

Total at 8 mg/l 16.61

__Without carbon filters when plant cost is \$14,000.__

Chlorine cost would be the same, \$1.71 and 2.74/day
Utilities the same 0.20/day
Labor less 2.50/day
Amortization less

$$\frac{14{,}000 \times 1.012}{10 \times 365} = \underline{3.90}$$

Total \$ $\underline{8.31}$ or $\underline{\$9.36}$

COST ESTIMATE FOR A 500,000 gpd, CONTINUOUS-FLOW, RE-TREATMENT SYSTEM WITH LOW CHLORINE RESIDUAL FOR PROTECTION AGAINST VEGETATIVE BACTERIA AND TOXIN

Item	Description	Cost
1	Building to house system - built of cement block, flat roof, no architectural treatment. Built by private contractor.	$ 18,000
2	2, 14" by-pass valve - 125# iron body wedge gate valve, $175.00 each.	350
3	4" by-pass drain valve - 125# iron body wedge gate valve	20
4	14" by-pass pipe and fittings	803
5	12" treatment entrance valve - 125# iron body wedge gate valve.	98
6	8" flow meter	3,900
7	Residual chlorine recorder	3,100
8	pH indicating and recording instrument	1,200
9	Temperature indicator and recorder	280
10	12" C.I. Flanged pipe and fittings. (within building)	1,824
11	Concrete chlorine contact tank, 25' x 12.5 x 12.5, 5-min. detention, complete with gravel, excavation, laying, and backfilling	8,500
12	7, pressure carbon filters with appurtenant piping and equipment.	22,000
13	Air compressor, if required.	250
14	12" by-pass valves for cleaning, flushing, and adjusting system.	196
15	Miscellaneous pipe and fittings.	300
		$60,821
	10% for furnishing and maintenance of equipment	6,082
	15% for installation estimate	9,000
	Total	$76,903

OPERATING COST

I. Chemical (when using a chlorine dose of 5 mg/l)

Chlorine - 0.5 x 8.33 x 5 = 20.8 lb/day at $0.12/lb = $2.50

Carbon (when filter dimensions are 8' in diameter and 2.5' in depth)

$$Q = (7)\ 8 \times 8\ \frac{\pi}{4} \times 2.5 = 879.2 \text{ cu.ft.}$$

Chlorine capacity = 20 lbs/cu.ft.

Cost per cu.ft. = $7.00

$$\text{Cost per day} = (7 \times 879.2)\ \frac{20.8}{20 \times 879.2} = 7.28$$

II.	Utilities		1.50
III.	Labor		14.00
IV.	Amortization		
	$\frac{76,903 \times 1.0125}{10 \times 365}$ =		21.30
		Total	$ 46.58

If 8 ppm residual is used.

Chemicals	Cl_2	8/5 x 2.50		4.00
	Carbon	8/5 x 7.28		11.65
Labor and Utilities				15.50
Amortisation				21.30
			Total	$52.45

COST ESTIMATE FOR A 1,000,000 gpd, CONTINUOUS-FLOW, RE-TREATMENT SYSTEM WITH LOW CHLORINE RESIDUAL FOR PROTECTION AGAINST VEGETATIVE BACTERIA AND TOXIN

Item	Description	Cost
1	Building to house system, built of cement block with flat roof and no arch. Treatment-private contractor	$ 32,000
2	18" by-pass valve - 125# iron body wedge gate valves	630
3	8" by-pass drain valve - 125# iron body gate valve	50
4	18" by-pass pipe and fitting	1,431
5	16" treatment entrance valve - 125# iron body gate valve	234
6	12" flow meter and controls	4,200
7	Residual chlorine recorder	3,100
8	pH indicator and recorder	1,200
9	Temperature indicator and recorder	280
10	16" C.I. flanged pipe and fittings	3,230
11	Concrete, chlorine contact tank, 24 x 17.5 x 17.5, 5-min. detention; complete with gravel, excavation, laying, and backfilling	14,000
12	14, pressure filters	42,000
13	Air compressor	250
14	16" by-pass valves for cleaning, adjusting, flushing plant	468
15	Miscellaneous pipe and fitting	450
	Total	$ 103,523
	Approximately 10% for furnishing and maintenance equipment	10,000
	Approximately 15% for installation	16,000
	Total	$ 129,523
	Use	$ 130,000

OPERATING COSTS

I. Chemical

A. Chlorine (when dose is 5 mg/l for average flow)

Q = 5 x 1 x 8.33 = 41.7 lb/day

42 lb/day x \$0.12/lb = \$ 5.04/day

B. Carbon

Assume 20 lb/cu.ft. chlorine capacity and dimensions of each unit are 8' in diameter and 2.5 in depth

$14 \times (8)^2 \frac{\pi}{4} \times 2.5 = 1758$ cu.ft.

$\frac{1758 \times 20}{42} = 837$ day (life of carbon)

Cost of Carbon = \$7.00 per cu.ft.

$\frac{1758 \times 7}{837} = \$14.70$

II. Utilities 2.00

III. Labor 20.00

IV. Amortization

$\frac{130,000}{10} \times \frac{1.0125}{365} =$ 36.00

Total \$ 77.74/day

For 8 ppm chlorine feed

Chemicals:

Chlorine = 8/5 x 5.04 = 8.07

Carbon = 8/5 x 14.70 = 23.50

Labor and utilities = 22.00

Amortization = 36.00

\$ 89.57

COST ESTIMATE FOR A 25,000 gpd, CONTINUOUS RE-TREATMENT SYSTEM WITH HIGH CHLORINE RESIDUAL FOR SPORE PROTECTION USING CONCRETE HOLDING TANK

Item		Cost
Building		$ 5,000.00
Flow meter and transmitter		375.00
Acid feed pump including tanks		1,180.00
Chlorine feed pump including tanks		1,153.00
Chlorine indicator, recorder, and alarm		3,000.00
pH indicating, recording and control		1,800.00
Temperature indicator and recorder		280.00
Chlorine contact tank		6,500.00
Carbon filter		1,900.00
Soda ash pump including tanks		850.00
pH indicator, recorder and controller		1,800.00
Miscellaneous		5,762.00
Installation		7,500.00
	Total	$37,100.00

Operating Cost

Chemicals (Carbon, \$1.82; Cl_2, \$2.15; H_2SO_4, \$0.782; Na_2CO_3,\$0.20; Calgon, \$0.0338)		\$ 4.98
Labor and utilities		5.50
Amortization $\frac{37,000 \times 1.0125}{365 \times 10} = 16.1$		10.30
	Total	\$ 20.78

COST ESTIMATE FOR A 100,000 gpd, CONTINUOUS, RE-TREATMENT SYSTEM WITH HIGH CHLORINE RESIDUAL FOR SPORE PROTECTION USING CONCRETE HOLDING TANK

Item		Cost
Building		\$7,000.00
Acid feed pump		2,180.00
Chlorine feed and proportioning meter		3,970.00
Chlorine recorder, indicator and alarm		3,000.00
pH indicator, recorder, control and alarm		1,870.00
Chlorine contact tank		13,500.00
Carbon filters pressure type		6,400.00
Soda ash pump		1,750.00
pH indicator, recorder, control and alarm		1,780.00
Miscellaneous		8,040.00
Installation		9,600.00
	Total	\$ 59,000.00

Operating Cost:

Chemicals (Cl_2, \$2.50; Acid, \$3.12; Na_2CO_3, \$0.78; Calgon, \$1.36; Carbon, \$7.28)		\$ 15.04/day
Labor and utilities		11.00
Amortization at 2.5% for 10 years	$\frac{1.0125 \times 59,000}{3650}$	16.40
	Total	\$ 42.44

COST ESTIMATE FOR A 500,000 gpd, CONTINUOUS, RE-TREATMENT SYSTEM WITH HIGH CHLORINE RESIDUAL FOR SPORE PROTECTION USING CONCRETE HOLDING TANK

Item		Cost
Building		$ 21,000.00
Flow meter and chlorine feed device		4,245.00
Acid feed pump including tanks		3,800.00
Chlorine indicator, recorder and alarm		3,100.00
pH indicator, recorder and controller		1,800.00
Temperature indicator and recorder		280.00
Chlorine contact tank, concrete		58,000.00
Carbon filters, pressure type		22,000.00
Soda ash pump including tanks		1,280.00
pH indicator, recorder and controller		1,800.00
Air compressor		250.00
Miscellaneous		17,725.00
Installation		22,370.00
	Total	$ 157,667.00
Operating Cost		
Chemicals (Cl_2, \$12.58; H_2SO_4, \$15.63; Na_2CO_3, \$3.92; Calgon, \$6.76; Carbon, \$36.41)		$ 75.20
Labor and Utilities		22.00
Amortization at 2.5% for 10 years	$\frac{1.0125 \times 172,000}{3650}$	43.70
	Total	$ 140.90/day

COST ESTIMATE FOR A 1,000,000 gpd, CONTINUOUS, RE-TREATMENT SYSTEM WITH HIGH CHLORINE RESIDUAL FOR SPORE PROTECTION USING CONCRETE HOLDING TANK

Item		Cost
Building		40,000.00
Flow meter and chlorine feed device		5,156.00
Acid feed pump including tanks		5,600.00
Chlorine residual indicator, recorder and alarm		3,100.00
pH indicator, recorder and controller		1,800.00
Temperature recorder		278.00
Chlorine contact tank		100.000.00
Carbon filters, pressure type		42,000.00
Soda ash pump including tanks		1,400.00
pH indicator, recorder and controller		1,800.00
Air compressor		325.00
Miscellaneous		33,441.00
Installation		39,000.00
	Total	$ 273,900.00 274,000.00
Operating Cost		
Chemicals		150.40
Labor and utilities		43.00
Amortization at 2.5% for 10 years	$\frac{274,000 \times 1.0125}{3650}$	76.00
	Total	$ 269.40

COST OF PRECHLORINATION FOR SPORE PROTECTION FOR A CONVENTIONAL TREATMENT PLANT

(AVG. FLOW = 0.5 MGD - MAX. FLOW 1.5 MGD)

Automatic flow proportioning prechlorinator (for a feed of 15 mg/l), chlorine feed cap. required: 15 x 1.5 x 8.33 = 187.5 lb/day and appurtenant equipment.

Insert nozzle 8" to proportion chlorine feed	$ 4,250.00
Two residual chlorine indicators and recorder with alarm, $3,200 each.	6,400.00
Dechlorination feed Max SO_2 feed: $\frac{64}{71}$ x 15 x 8.33 x 1.5 = 169 lb/day	
Use chlorinizer with appurtenant equipment est.	2,500.00
Estimate of piping required	1,000.00
Equipment total	14,150.00

Daily Operating Cost

Chlorine = 62 x 0.12	7.45
Sulfur dioxide = 57 x 0.12 =	6.83
Amortization = $\frac{14,150 \times 1.012}{3650}$ =	3.92
Labor and utilities =	4.00
Total	$ 22.20

COST OF PRECHLORINATION FOR SPORE PROTECTION FOR A CONVENTIONAL TREATMENT PLANT
(AVG. FLOW 1 MGD - MAX. FLOW 3 MGD)

Item	Cost
Automatic flow proportioning prechlorinator (15 mg/1 dose) Chlorine feed capacity required: $15 \times 3 \times 8.33 = 375$ lb/day and necessary equipment.	
12" insert nozzle flow meter to proportion chlorine indicator, recorder, totalizer	$ 5,160.00
Two residual chlorine indicators, recorders and alarms $3,200 each.	6,400.00
Dechlorination feed Max SO_2 feed: $\frac{64}{71} \times 15 \times 8.33 \times 3 = 338$ lb/day	
Use chlorinizer, programing feed with appurtenant equipment	3,000.00
Estimate additional piping required	1,500.00
Total Equipment	$ 16,060.00

Daily Operating Cost

Chlorine = 125×0.12 =	15.00
Sulfur dioxide = 113×0.12 =	13.60
Amortization = $\frac{16,060 \times 1.012}{3650}$ =	4.46
Labor and utilities =	4.00
Total, approximate	$ 37.10

COST OF PRECHLORINATION FOR SPORE PROTECTION FOR A CONVENTIONAL TREATMENT PLANT
(AVG. FLOW 5 MGD - MAX. FLOW 15 MGD)

Item	Cost
Automatic flow proportioning prechlorinator (15 mg/l dose) Chlorine feed capacity required: $15 \times 15 \times 8.33 = 1875$ lb/day Use chlorinizer 200 lb/day, pneumatic control including scales and necessary equipment.	
16" insert nozzle with totalizer, indicator and recorder	$ 7,500.00
Two, residual chlorine indicator, recorder with alarm $3,200 each.	6,400.00
Dechlorination feed Max. SO_2 feed: $\frac{64}{71} \times 15 \times 8.33$	
Use chlorinizer 2000 lb/day capacity, programing feed with scales and necessary equipment	5,000.00
Estimate additional piping required	2,000.00
Total, equipment	$20,900.00
Daily Operating Cost	
Chlorine = 625×0.03 =	50.00
Sulfur dioxide = 567×0.08 =	58.00
Amortization = $\frac{20,900 \times 1.012}{3650}$	4.00
Labor and utilities	8.00
Total	$ 120.00

COST OF PRECHLORINATION FOR SPORE PROTECTION FOR A CONVENTIONAL TREATMENT PLANT
(AVG. FLOW 10 MGD - MAX. FLOW 30 MGD)

Item	Cost
Automatic flow proportioning chlorinizer (15 mg/1 dose) Chlorine feed capacity required: 15 x 30 x 8.33 = 3750 lb/day Use chlorinizer 4000 lb/day, pneumatic control including scales and necessary equipment	
24" insert nozzle with totalizer, indicator and recorder	$ 11,200.00
Two, residual chlorine indicator, recorder with alarm, $3200 each.	6,400.00
Dechlorination feed Max. SO_2 feed: $\frac{64}{71} \times 15 \times 8.33 \times 30 = 3380$ lb/day	
Use chlorinizer 4000 lb/day capacity, programing feed with scales and necessary equipment	8,000.00
Estimate additional piping required	3,000.00
Total, equipment	$ 28,600.00
Daily Operating Cost	
Chlorine = 1250 lb/day x 0.08	100.00
Sulfur dioxide = 1130 lb/day x 0.08	93.00
Amortization = $\frac{28,600 \times 1.012}{3650}$	7.93
Labor and utilities	15.00
Total, approximate	$ 216.00

APPENDIX F

Monitoring for BW and CW Agents in Water With Fish

by

Quentin H. Pickering, Aquatic Biologist
Croswell Henderson, Aquatic Biologist

INTRODUCTION

With the development of more toxic BW and CW agents it becomes increasingly important to explore all methods for the detection, identification and measurement of contaminants in water supplies. This work was initiated to explore the possibility of using fish for continuous monitoring to detect highly toxic BW and CW agents in water.

Chemical methods have been developed for the detection and measurement of certain CW agents in water. However, the use of such methods to continuously monitor water supplies would be somewhat difficult and costly. Also, other contaminants may be used for which chemical methods have not been developed. As fish are extremely sensitive to certain toxicants, it was believed that a rapid and inexpensive continuous detection system could be developed by using modifications of fish bioassay procedures.

After initial detection by fish, other methods could be used to further estimate the type and quantity of contaminant. Fish, though not truly selective, do have certain physiological reactions and time of effect-concentration relationships which may be useful in identifying and estimating concentrations of contaminant.

TEST FISH

The fish used for monitoring must be able to live in the normal water supply, tolerate handling, be small and uniform, and react quickly to concentrations of the contaminant that would be harmful to man.

Tests were made with five species to determine their suitability for monitoring purposes. Of these the fathead minnow, Pimephales promelas, ranging in length from 50 to 65 mm and weighing about 1 to 1.5 grams, were used in most of the tests. Bluegills (Lepomis macrochirus), green sunfish Lepomis cyanellus), and goldfish (Carrassius auratus) of similar size and weight were also used as were guppies (Lebistes reticulatus) that weighed approximately 0.1 gram and ranged from 20 to 32 mm long. All of these species proved suitable for use in monitoring systems.

TEST CONDITIONS

Generally, the dissolved oxygen and pH of drinking waters are such that they will not adversely affect the test fish. However, care must be taken to remove any toxic material such as chlorine and some temperature adjustments may be necessary. Concentrations as low as 0.5 mg/l of free available chlorine may be toxic to some species of fish. Of the species tested, bluegills and green sunfish were the most resistant. Chlorine is somewhat more toxic in soft water and at low pH water.

Dechlorination of test waters can be accomplished by aeration and exposure to sunlight, by passage through activated carbon, or by adding a reducing agent. The selected reducing agent, sodium thiosulfate, added continuously, served as the best method and agent for a continuous monitoring system. It takes about 7 mg of sodium thiosulfate ($Na_2S_2O_3$) to reduce 1 mg of chlorine, and, since it is highly soluble it can be added continuously into the influent of a test aquarium. Sodium thiosulfate is non-toxic to fish in the required concentrations.

The optimum temperature range for warm water fish is from 20 to 28°C. They can tolerate gradual changes between 4° and 34°C but abrupt changes of over 5°C should be avoided. Ordinary aquarium heaters will help to moderate extremes and make test reactions more valid.

Dissolved oxygen levels should remain above 4 mg/l during the tests. Lower levels may cause fish mortality or abnormal sensitivity to some toxicants.

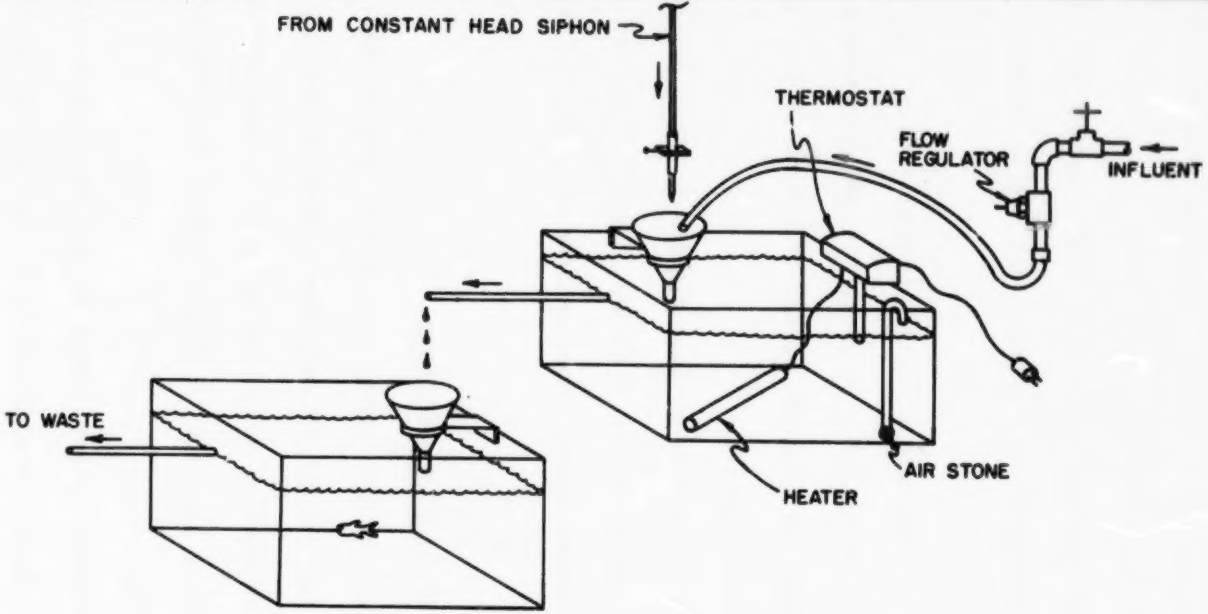
Most species of fish can tolerate pH levels between 5 and 9 but pH changes can greatly influence the toxicity of chemicals. No recommendation is made for pH control, however, an accurate record of the pH is desirable for subsequent interpretation of results.

False alarms caused by heavy metals, insecticides or other toxicants seem less likely than trouble arising from chlorine. Copper, lead and zinc can be toxic to fish in soft water above concentrations of 0.05, 0.2 and 0.5 mg/l respectively.

MONITORING APPARATUS

The simplest type of monitoring system that can be used is the direct flow of water from a tap through an aquarium containing fish. If 5 to 10 three-inch fish are used, a volume of 10 to 20 liters with a replacement time of 1 to 2 hours is adequate to get a rapid response of fish to possible contaminants.

Modifications are necessary in most cases to dechlorinate and control water temperature. Figure 1 shows the apparatus used during this project to monitor Cincinnati tap water which contains a small chloramine residual. Accurate records of temperature, D.O., pH, alkalinity and hardness are



FROM CONSTANT HEAD SIPHON
THERMOSTAT
FLOW
REGULATOR
INFLUENT
TO WASTE
AIR STONE
HEATER

CONTINUOUS FLOW MONITORING APPARATUS

Figure 1

useful if any estimates of concentration of possible contaminant are to be made.

Very little maintenance is required for this continuous flow system. Dead or diseased fish should be removed and replaced from fresh stock. The fish should be fed about three times a week with a dry food and the aquarium cleaned occasionally. The thiosulfate solution will have to be prepared about twice a week. A stock of a reasonable number of test fish should be kept on hand.

TOXICITY OF CW AGENTS

Nerve gases were considered the chemical agents with the greatest potential for use in contaminating water. Therefore, the nerve gas, Sarin, and a few simulants such as the organic phosphorus insecticides were used to determine the effectiveness of a continuous monitoring system.

The Sarin (isopropyl methyl phosphono-fluoridate) used in this study was obtained from the Army Chemical Center in Maryland. Static (non-renewed solutions) as well as continuous flow bioassays were made with different types of test water at a temperature of 25°C.

A summary of static bioassay results with fathead minnows is given in Table 1. These 24, 48 and 96-hour TLm (median tolerance limit - concentration that causes 50% mortality of the test fish) values indicate Sarin to be about seven times more toxic in soft than hard water. It has been stated that above pH 6.5 the rate of hydrolysis of Sarin increases ten times per unit increase in pH. So the difference in toxicity is probably due to the more rapid breakdown of the Sarin in the hard water with higher pH.

TABLE 1

COMPARISON OF THE TOXICITY OF SARIN TO FATHEAD MINNOWS IN SOFT AND HARD WATER

TL_m for Sarin

(ug/liter)

Date	SOFT (pH 7.4) 24 hrs.	48 hrs.	96 hrs.	HARD (pH 8.2) 24 hrs.	48 hrs.	96 hrs.
11/15/58	5.6	4.2	4.2	24.0	24.0	24.0
12/27/56	4.8	4.4	4.4	14.5	14.5	14.5(1)
4/15/57	8.0	5.0	5.0	41.0	41.0	41.0
4/20/57	10.0	10.0	4.6	-	-	-
6/13/57	-	-	-	43.7	43.7	43.7
7/25/57	4.6	4.2	4.2	23.3	23.3	23.3(2)
8/1/57	7.0	5.0	4.6	-	-	-
8/28/57	5.6	4.1	3.9	24.5	23.7	23.7
9/10/57	-	-	-	22.0	21.5	21.5
9/16/57	-	-	-	24.0	24.0	24.0
10/3/57	-	-	-	32.0	32.0	32.0
10/3/57	-	-	-	45.5	45.5	45.5
Average	6.5	5.3	4.4	32.1	31.9	31.9

(1) Dilution water with exceptionally low pH (7.9) - not included in average.

(2) Bioassay with dechlorinated Cincinnati tap water (pH 8.3; alkalinity 64 mg/l; hardness 186 mg/l, not included in average.

In the static bioassays with hard water there is no significant difference between the 24 and 96-hour TL_m values. Apparently, after the first few hours the Sarin has hydrolyzed to sub-lethal concentrations and if the fish do not die in the first 24-hours they will survive at least 96-hours. On the other hand, in the tests with the soft water, there is an increase in the toxicity from 24 to 96-hours which indicates a less rapid breakdown of Sarin and a possible accumulative or chronic effect on fish. Minor differences in 96-hours TL_m values obtained under similiar test conditions are due to the biological variation in different lots of fish.

Table 2 shows the variation in resistance of five species of test fish to Sarin in soft and hard water. Bluegills were the most sensitive whereas goldfish were the most resistant species.

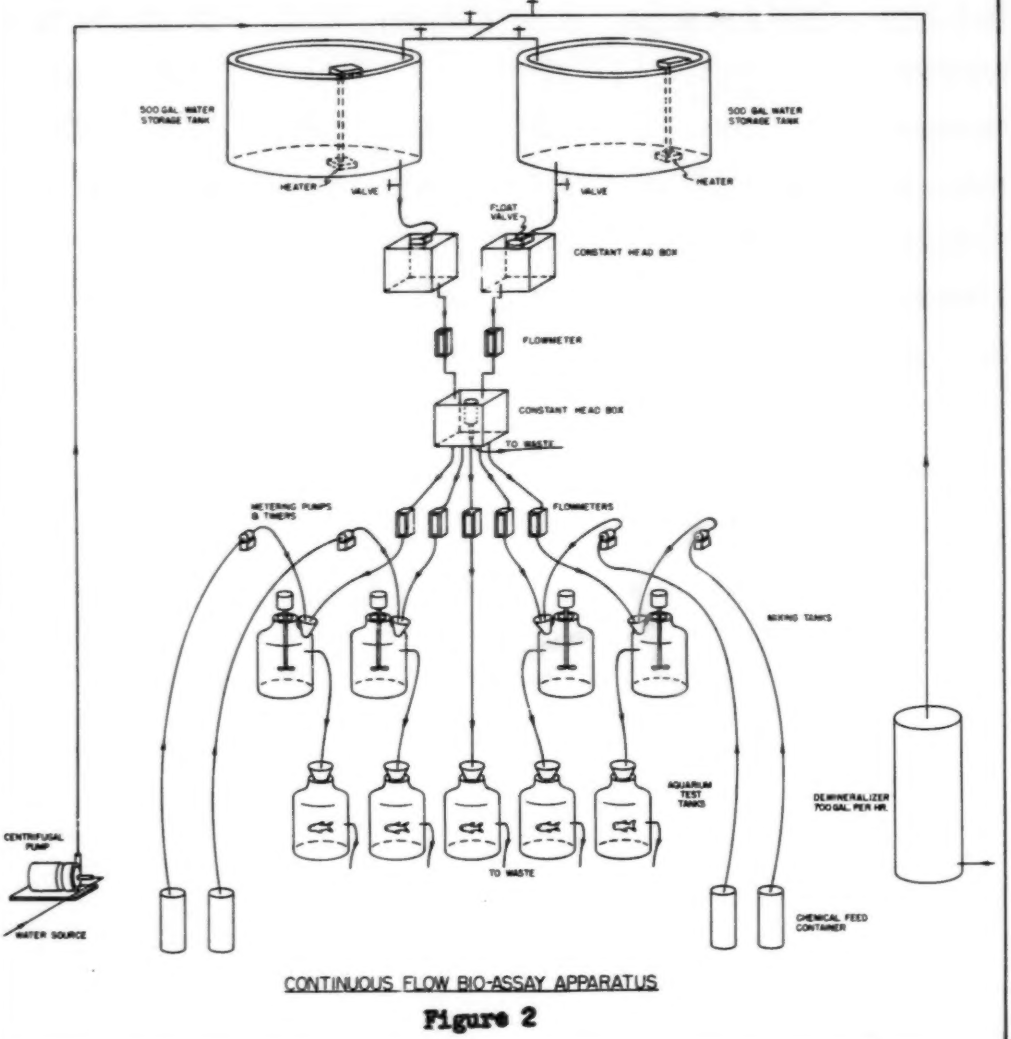
In non-renewed solutions, the concentration of a toxicant may be reduced, in time, by hydrolysis, oxidation or other chemical change. An apparatus was designed (Figure 2) to conduct bioassay in continuously renewed test solutions. Various operational controls were built in for maintaining different experimental conditions.

The comparative results between continuous-flow and static bioassays (Table 3) show that Sarin is considerably more toxic when test solutions are constantly renewed. This would indicate a considerable reduction in hydrolysis in the continuous flow tests (solutions renewed every 200 minutes). The apparant differences in toxicity in soft and hard waters were greatly reduced from that shown by static bioassays. Sarin, however, was still somewhat more toxic in soft water. Differences in 24, 48 and 96-hour TL_m values in both hard and soft waters under continuous flow conditions indicate an accummulative effect of Sarin on fish.

TABLE 2

COMPARATIVE TOXICITY OF SARIN TO FIVE SPECIES OF FISH IN SOFT AND HARD WATERS

Test Fish	Dilution Water	TL_m for Sarin (µg/liter) 24 hrs.	48 hrs.	96 hrs.
Bluegills	Soft	7.5	3.2	3.2
	Hard	23.5	23.5	23.5
Green sunfish	Soft	4.6	4.2	4.2
	Hard	15.2	15.2	15.2
Fathead minnows	Soft	6.5	5.3	4.4
	Hard	32.1	31.9	31.9
Guppies	Soft	8.3	7.2	7.2
	Hard	21.0	14.5	13.8
Goldfish	Soft	16.1	11.8	9.8
	Hard	-	-	-


500 GAL WATER STORAGE TANK
500 GAL WATER STORAGE TANK
HEATER
VALVE
VALVE
HEATER
FLOAT VALVE
CONSTANT HEAD BOX
FLOWMETER
CONSTANT HEAD BOX
TO WASTE
METERING PUMPS & TIMERS
FLOWMETERS
MIXING TANKS
AQUARIUM TEST TANKS
DEMINERALIZER 700 GAL. PER HR.
CENTRIFUGAL PUMP
TO WASTE
WATER SOURCE
CHEMICAL FEED CONTAINER

CONTINUOUS FLOW BIO-ASSAY APPARATUS

Figure 2

TABLE 3

COMPARATIVE TOXICITY OF SARIN SOLUTIONS UNDER STATIC AND CONTINUOUS FLOW CONDITIONS

TL_m (μg/liter Sarin)

Test Fish	Type of Dilution Water	Continuous Flow			Static		
		24 hrs.	48 hrs.	96 hrs.	24 hrs.	48 hrs.	96 hrs.
Fatheads	Soft	2.5	2.1	1.4	7.2	7.2	7.2
Fatheads	Soft	4.0	2.4	0.83	4.6	4.2	4.2
Fatheads	Cincinnati tap	8.8	5.4	2.3	23.3	23.3	23.3
Fatheads	Hard	5.8	3.5	3.1	42.0	42.0	42.0
Fatheads	Hard	6.2	6.2	4.2	43.7	43.7	43.7
Goldfish	Soft	10.2	6.4	4.1	16.3	13.0	13.0

TIME OF EFFECT - CONCENTRATION RELATIONSHIPS

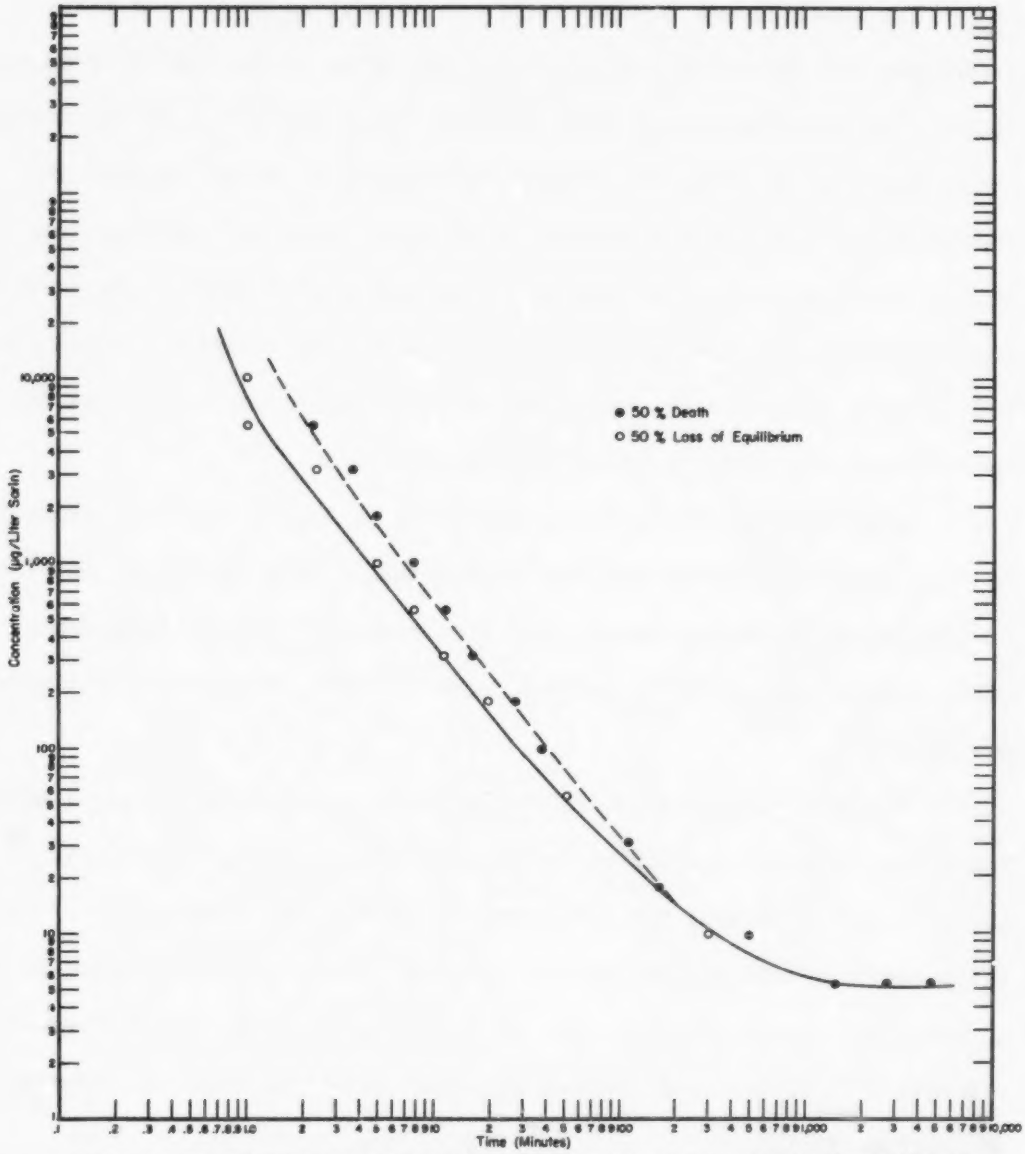
The usual 24 and 96-hour tests are helpful in developing assay techniques and comparing toxicants, but for water monitoring it is necessary to know the significance of short exposure times such as 10 to 60 minutes.

The time of response (loss of equilibrium or death) of fish is dependent upon the concentration of a toxicant, with the response time usually more rapid with increasing concentration of chemical. By exposing fish to known concentrations of toxicant, a time of effect-concentration relationship can be established (Figure 3). Unknown concentrations can thus be estimated from the time of fish reaction.

Since the human tolerance of Sarin is 0.5 mg/l, fish were exposed to this concentration and reaction time noted. Using the 50 percent loss of equilibrium as an end point, this concentration could be detected in eight minutes; using the 50 percent death criteria, the detection time was twelve minutes.

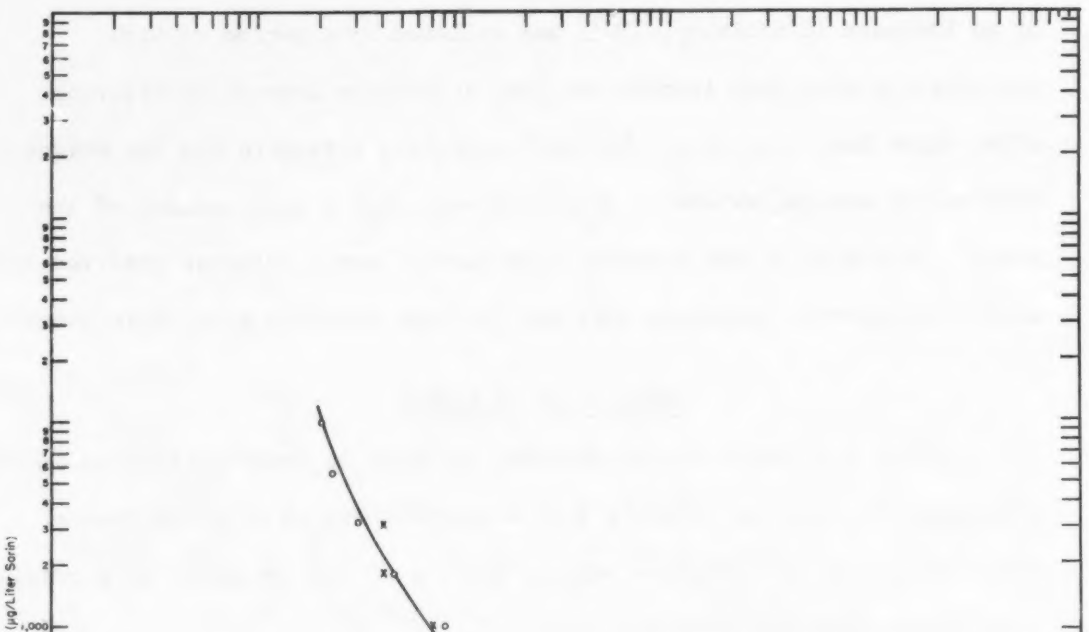
The time of effect-concentration curve presented in Figure 4 shows the effect of water quality on the time of 50 percent death of fish. Above 56 µg/l of Sarin, the water quality (within the range studied) had little or no effect on the reaction time of fathead minnows. Below 56 µg/l of Sarin and with a reaction time of 70-minutes or more, the difference in the rate of hydrolysis of the two solutions was significant in terms of toxicity to fish.

The general response of fish to Sarin is somewhat similar in all concentrations, but of course each sequence of events is of shorter duration in the higher concentrations. With fathead minnows the initial



EFFECT CURVE SHOWING THE TIME OF 50 PER CENT LOSS OF EQUILIBRIUM AND DEATH OF FATHEAD MINNOWS EXPOSED TO KNOWN CONCENTRATIONS OF SARIN

Figure 3



TIME OF EFFECT-CONCENTRATION CURVE SHOWING THE TIME OF 50 PER CENT DEATH OF FATHEAD MINNOWS EXPOSED TO KNOWN CONCENTRATIONS OF SARIN IN SOFT AND HARD WATER

Figure 4

response was an increase in the depth and rate of respiration followed by an increase in activity. This was followed by a period of high excitability with body tremors and then a complete loss of equilibrium after which they soon died. The most conspicious feature was the exaggerated respiratory action, extension of gill covers, and a wide opening of the mouth. Extension of the pictoral fins forward was a response observed with organic phosphorus compounds that had not been observed with other chemicals.

TOXICITY OF BW AGENTS

While fish would not be expected to react to human disease producing organisms, it appeared possible that a reaction may be obtained from a neuro-toxin such as botulinum toxin. The use of this material as a possible water contaminant had been suggested.

Samples of partially purified Clostridium botulinum type A toxin, which assayed 3.2×10^8 to 6.8×10^8 mouse IP LD_{50} per milliliter, were obtained from Fort Detrick.

In bioassays conducted with this toxin, fathead minnows survived concentrations of 102,000 mouse LD_{50}/ml for 24 hours, and concentrations of 17,000 mouse LD_{50}/ml for 96-hours. Since these concentrations are considerably above dangerous levels in drinking water, it does not appear feasible to use fish for detecting botulinum toxin.

CONCLUSIONS

1. It is feasible to use fish for detecting nerve gases such as Sarin in water supplies since they react quickly and distinctively to concentrations far below the tolerance limits for humans.
2. A continuous-flow-through apparatus is the most sensitive and practical device for water monitoring. Standard static bioassays are not as sensitive.
3. If chlorine is present in the water, it must be removed, preferably with sodium thiosulfate.
4. Temperature control with heaters is easily arranged, and pH and water hardness records would be helpful when interpreting results.
5. Sarin is most toxic in low pH soft waters.
6. Fathead minnows, bluegills and green sunfish are the most sensitive to Sarin, and guppies and goldfish are the most resistant.
7. Human tolerance levels of Sarin in drinking water (0.g mg/l) can be detected by fish reaction in 8 to 12-minutes.
8. Time of effect-concentration relationship can be used to estimate concentrations of toxicant in water. Characteristic physiological responses of fish may be used to help identify types of compounds.
9. Botulinum toxin in concentrations expected to be dangerous in drinking water did not cause a response in fish.